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THE MANNED LUNAR EXPLORATION

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CONTENTS

Section	Page
1. APOLLO MISSION DESCRIPTION By Dr. William A. Lee	1
2. SPACECRAFT DESCRIPTION By O. E. Maynard	11
3. SPACECRAFT CAPABILITY FOR APOLLO SCIENTIFIC EXPERIMENTS By John Eggleston	21
4. LUNAR SURFACE ACTIVITIES By Curtis C. Mason and Elbert A. King, Jr.	31
5. SPACESUIT CAPABILITIES By Edward Hayes	41
6. ASTRONAUT TRAINING By Neil A. Armstrong	43
7. ASTRONAUT TRAINING IN GEOSCIENCES By Dr. Ted H. Foss	49
8. MSC RESEARCH ON LUNAR SURFACE EXPERIMENTS By John E. Dornbach	53
9. LUNAR ORBITAL EXPLORATION By James H. Sasser	65
10. SPACECRAFT CAPABILITY FOR LUNAR ORBITAL SURVEY By Donald Bresie and Rene A. Berglund	71
11. LUNAR ATMOSPHERIC MEASUREMENTS By Dallas E. Evans	79

FIGURES

	Page
1. APOLLO MISSION DESCRIPTION	
1-1 Merritt Island launch area at Cape Kennedy	4
1-2 "Crawler"	4
1-3 Launch pad	4
1-4 NASA Saturn vehicles	4
1-5 Spacecraft launch configuration	5
1-6 Earth launch phase	5
1-7 Apollo launch	5
1-8 Parking orbit around earth	5
1-9 Insertion into translunar trajectory	6
1-10 Injection completed	6
1-11 CSM separation from adapter	6
1-12 Spacecraft rotation	6
1-13 Lunar landing phase	7
1-14 Spacecraft approaches moon	7
1-15 Entry into lunar orbit	7
1-16 LEM separation	7
1-17 Apollo landing area	8
1-18 Lunar surface activities	8
1-19 Lunar launch phase	8
1-20 Launch for ascent to lunar orbit	8
1-21 LEM rendezvous with CM	9
1-22 LEM-CM docking maneuver	9
1-23 Earth landing phase	9
1-24 Orientation of CM-blunt heat shield forward	9
1-25 CM reentry	10
1-26 Deployment of parachutes for landing	10
2. SPACECRAFT Description	
2-1 Spacecraft in flight	18
2-2 Command module living area	18
2-3 Service module	18
2-4 Lunar excursion module	18
2-5 Lunar launch	19
2-6 LEM ascent stage - plan view	19
2-7 LEM ascent stage - side view	19
2-8 LEM crew station	19
2-9 Communication links	20

3. SPACECRAFT CAPABILITY FOR APOLLO SCIENTIFIC EXPERIMENTS

3-1	Apollo Scientific payload	28
3-2	Scientific equipment stowage - LEM	28
3-3	Scientific equipment stowage - CM	28
3-4	Common volume requirements	28
3-5	(a) Typical payload breakdown	29
	(b) Typical payload breakdown (concluded)	29
3-6	Schedule for typical instrument development	29

4. LUNAR SURFACE ACTIVITIES

4-1	Typical 35-hour-stay time cycle	39
4-2	Typical mission schematic	39
4-3	Exploration traverse equipment	39

6. ASTRONAUT TRAINING

6-1	50-foot basic centrifuge	47
6-2	Apollo centrifuge equipment	47
6-3	Tropical survival training	47
6-4	Apollo mission simulator	47
6-5	Free flight lunar lander	48
6-6	Translation and docking simulation	48

7. ASTRONAUT TRAINING IN GEOSCIENCES

7-1	Astronauts M. Collins and R. Chaffee mark contact between rock formations on an aerial photograph during the Grand Canyon field trip. NASA geologist E. A. King supervises	51
7-2	Astronaut W. Anders, NASA geologist Dr. T. H. Foss, and astronaut A. Shepard discuss rock structures near the bottom of the Grand Canyon	51
7-3	Dr. William Muehlberger of the University of Texas and astronauts Scott Carpenter and Charles Conrad examine deformed sedimentary rocks in the Marathon Basin of West Texas	51
7-4	A group of Astronauts and geologists walk over a lava flow near Flagstaff, Arizona	51
7-5	Astronaut C. C. Williams, Dr. E. D. Jackson of the USGS, and Astronauts Frank Borman and Eugene Cernan examine features of a lava flow near Flagstaff, Arizona	52

	Page
7-6 Astronauts take a gravity meter reading at Phil- mount Ranch, New Mexico	52
7-7 Dr. Charles Pillmore of the USGS instructs astro- nauts Elliot See and Richard Gordon in the use of the Jacob's Staff at Philmont Ranch, New Mexico	52
8. MSC RESEARCH ON LUNAR SURFACE EXPERIMENTS	
8-1 Tl study-flow chart	63
8-2 Lunar surface simulation	63
8-3 LEM mock up on Site I lunar surface simulation . .	63
9. LUNAR ORBITAL EXPLORATION	
9-1 Aristarchus - photo	69
9-2 Aristarchus - USAF chart	69
9-3 Aristarchus - new USAF drawing	69
9-4 Experimental composite color photograph	69
9-5 Photomosaic of moon surface	70
10. SPACECRAFT CAPABILITY FOR LUNAR ORBITAL SURVEY	
10-1 Transit trajectory	77
10-2 Lunar trajectory	77
10-3 Good lighting coverage	77
10-4 Launch configuration	77
10-5 Lunar orbit configuration	78
10-6 Equipment stage - inboard profile	78
10-7 Surface probe	78
10-8 Operation after impact	78

FOREWORD

This document contains the speeches delivered by MSC personnel at the Manned Lunar Exploration Symposium on June 15 and 16, 1964, held at NASA Manned Spacecraft Center, Houston, Texas. Following the technical program, subgroup meetings of prospective experimental teams were held on June 17 and 18, 1964. Warren Gillespie, Jr. of MSC served as symposium manager.

1. APOLLO MISSION DESCRIPTION

By Dr. William A. Lee

This paper describes a typical Apollo lunar landing mission. The particular example chosen provides a 24-hour stay on the lunar surface and has a total duration of slightly more than eight days.

EARTH LAUNCH PHASE

Launch will be from the Merritt Island Launch Area at Cape Kennedy (fig. 1-1). The Saturn V booster and the Apollo spacecraft are assembled within this building and then moved to one of the launch pads by a large tractor-like device called a "crawler" (fig. 1-2). On the launch pad (fig. 1-3) the propellant tanks are filled, the crew enters, and the entire vehicle is given a final checkout.

It is difficult to convey the size of the total vehicle in its normal setting and figure 1-4 offers a more familiar object for comparison. Plans are being made to launch into space a structure over 350 feet tall, weighing approximately 3,000 tons at launch. The three crewmen are contained in the small conical portion at the top, called the command module.

Comment should be made on the arrangement of the spacecraft at launch because this arrangement dictates a number of the maneuvers which will take place later in the mission (fig. 1-5). At launch the three crewmen are located in the command module. They will remain there throughout most of the trip, and it is this portion of the spacecraft which will return to earth. Immediately below the command module is the service module containing, primarily, a rocket engine and propellants, as well as some miscellaneous supplies. The service module will provide the thrust required to slow the spacecraft, placing it in a lunar orbit, and later, to send the command module out of orbit and back toward earth. Below the service module is an adapter which connects the spacecraft to the upper stage of the Saturn V booster. Within the adapter is the third module of the spacecraft, the lunar excursion module or LEM. The LEM is essentially a second spacecraft and is designed to carry two of the three crewmen from lunar orbit down to the surface of the moon and then back to a rendezvous with the command and service modules in lunar orbit. In the launch configuration, it is tucked away within the adapter and is not accessible to the crew.

Returning now to the mission sequence, the events occurring during the first day are shown in figure 1-6. The spacecraft is launched (fig. 1-7) into a 100 nautical miles circular parking orbit around the earth (fig. 1-8). Still attached to the upper stage of the Saturn V, the orbiting spacecraft is checked once again while it completes between one and three orbits. The upper stage of the Saturn then burns again (fig. 1-9) to insert the spacecraft onto a translunar trajectory.

After the injection maneuver (fig. 1-10) has been completed, the command and service modules separate from the adapter (fig. 1-11), leaving the LEM attached to the Saturn stage. The spacecraft is rotated 180° (fig. 1-12) and docks with its forward hatch mated to the LEM hatch. The Saturn stage is jettisoned, and the spacecraft travels toward the moon in the docked configuration.

LUNAR LANDING PHASE

The planned translunar trajectories (fig. 1-13) vary in duration between 62 and 75 hours, depending on the earth-moon relationship at the time of the mission. For the example chosen, it is $66\frac{1}{2}$ hours. Up to four midcourse corrections (fig. 1-14) may be required during this period.

Near the point of closest approach to the moon, the service module engine slows the spacecraft (fig. 1-15) and places it in an 80 nautical miles circular orbit around the moon. Two crew members transfer into the LEM. Its equipment is activated and tested and after two lunar orbits have been completed, the LEM separates (fig. 1-16) from the command service modules and uses its engine to place it on a descent trajectory. As the LEM approaches the landing site, a second burn of the descent engine is begun and continued until a few seconds before landing.

The landing area (fig. 1-17), accessible to the Apollo spacecraft for the initial missions, is roughly a rectangle 90° wide and 10° high, centered on the near-earth face of the moon. The boundaries are determined by operational and safety considerations and may be modified significantly for later missions. Specific landing sites within this rectangle have not yet been selected. The choice, for the initial missions, will be dictated largely by safety considerations and by information obtained from the unmanned lunar probes. Initial landings will be made in sunlight in order to enhance the pilot's ability to observe and avoid local obstacles during landing.

The detailed capabilities of the system for lunar surface activities (fig. 1-18) will be described later. The LEM can remain on the

surface up to 44 hours, but probably will be restricted to shorter stay-times for the early missions. For the sample mission presented here, a 24-hour stay was assumed.

LUNAR LAUNCH PHASE

The lunar launch events are depicted in figure 1-19. As figure 1-20 indicates, the LEM is a two-stage vehicle and the descent stage serves as a launch platform for the ascent to lunar orbit. Approximately one hour after launch, the LEM will rendezvous with the third crew member who has remained in orbit (fig. 1-21). The vehicles are docked again (fig. 1-22) and the crew, data and samples are transferred to the command module. The LEM is left in lunar orbit and the service module engine propels the command module back toward earth.

EARTH LANDING PHASE

Return trajectories may range from 85 to 115 hours. In this example, $92\frac{1}{2}$ hours are required. Another series of up to four mid-course corrections may be used during the return flight. (See fig. 1-23.)

Just before the spacecraft strikes the atmosphere (fig. 1-24), the service module is jettisoned and the command module oriented with the blunt heat shield forward. During entry (fig. 1-25) the pilot maneuvers the spacecraft to assure landing at the designated recovery point. Finally, a set of three parachutes are deployed and the spacecraft descends to the water (fig. 1-26). Crew, samples and spacecraft are retrieved from the surface of the ocean by the recovery ship, in this case, some 400 miles east of Hawaii.

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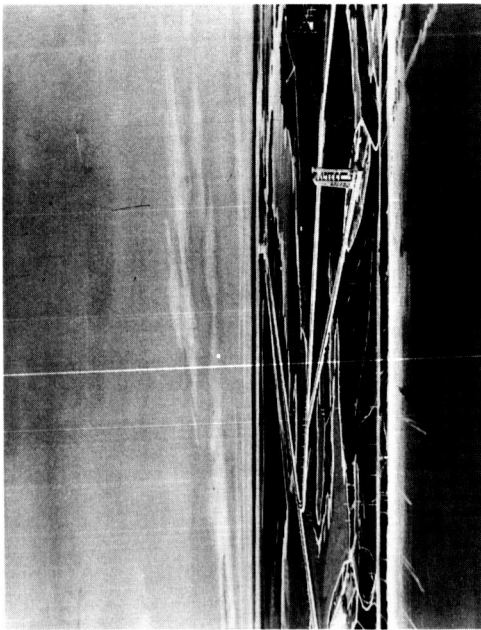


Figure 1-1

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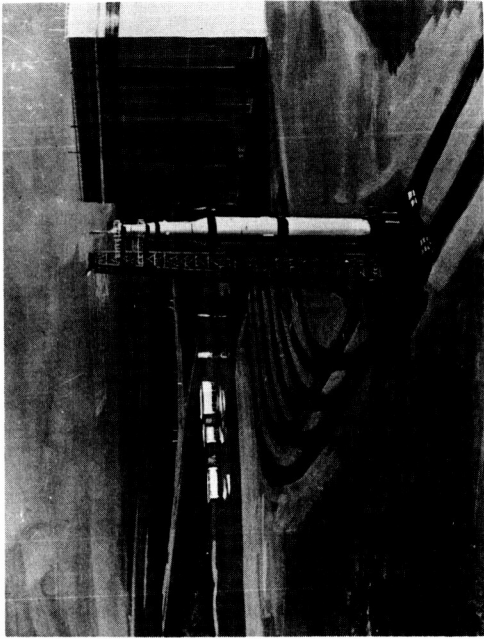


Figure 1-2

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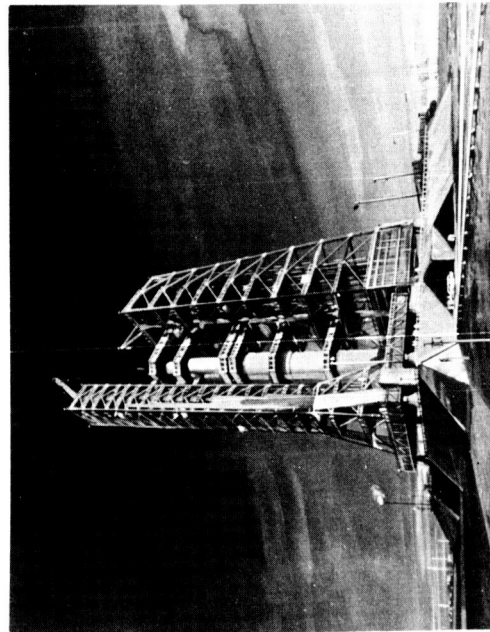


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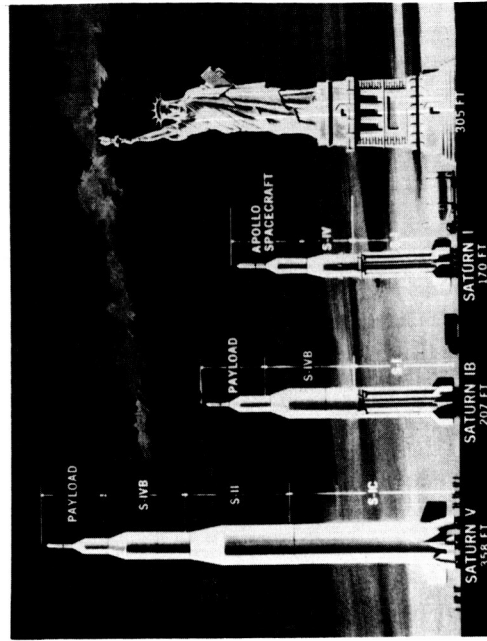


Figure 1-4

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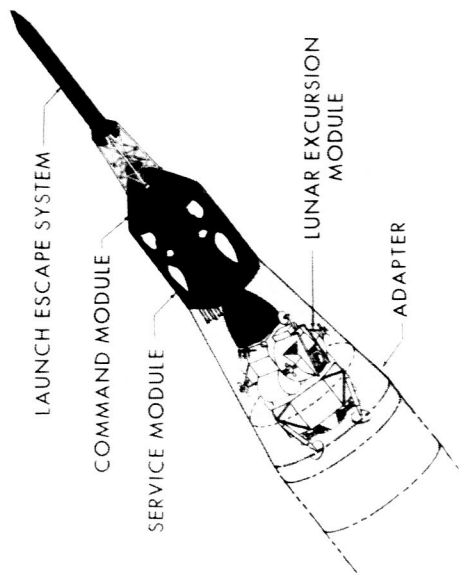


Figure 1-5

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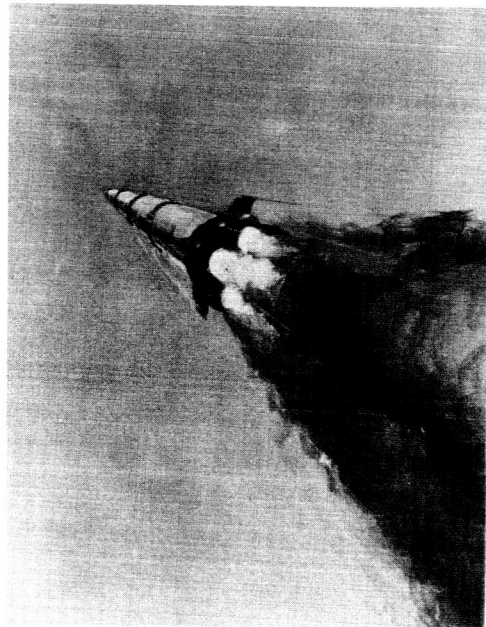


Figure 1-7

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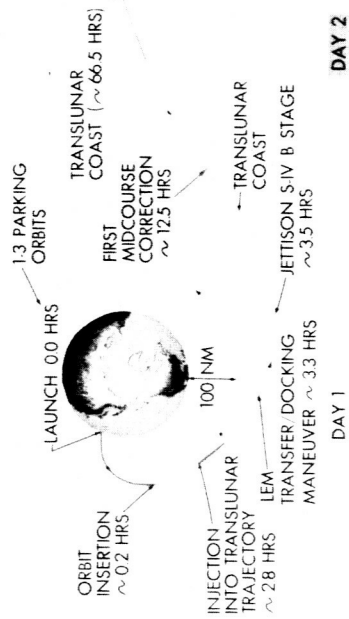


Figure 1-6

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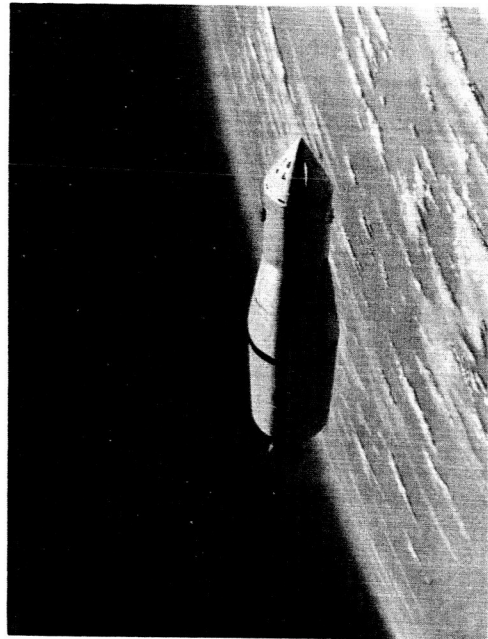


Figure 1-8

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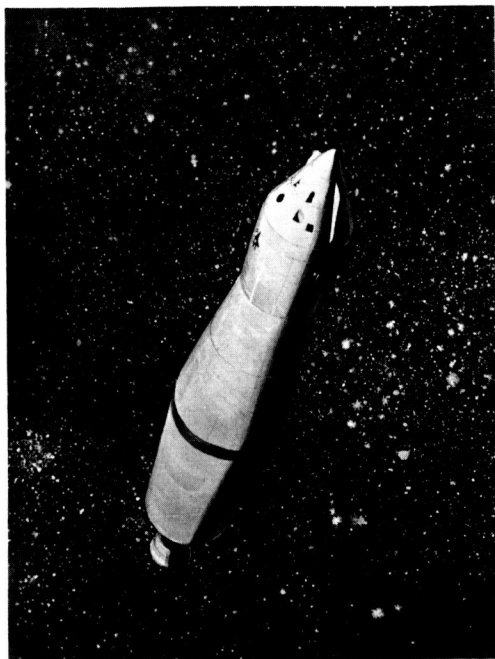


Figure 1-10

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Figure 1-12

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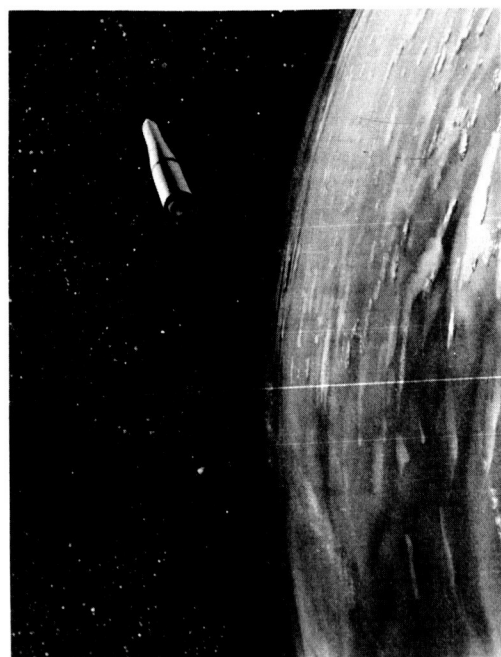


Figure 1-9

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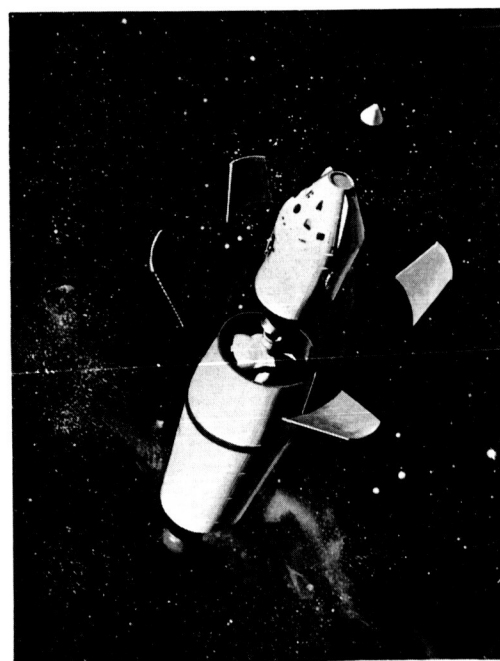


Figure 1-11

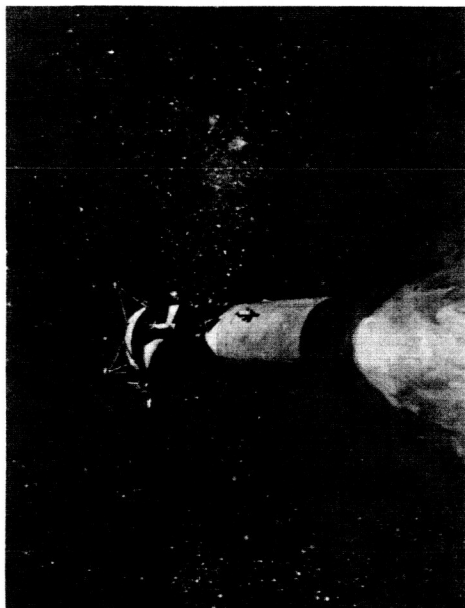


Figure 1-14

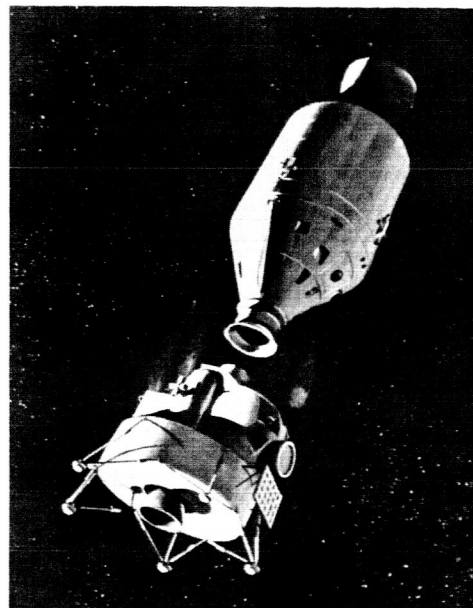


Figure 1-16

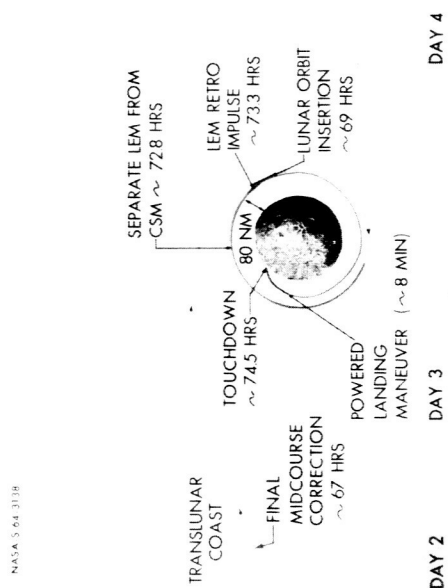


Figure 1-13



Figure 1-15

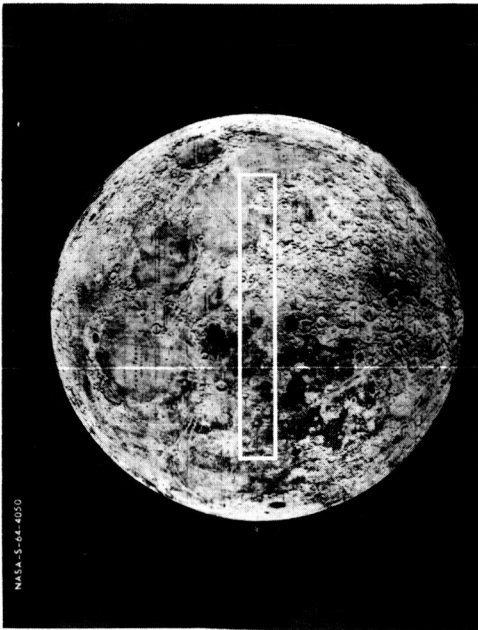


Figure 1-17

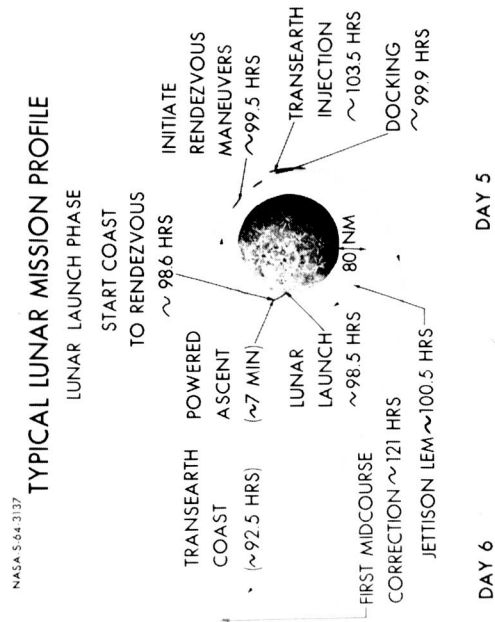


Figure 1-19

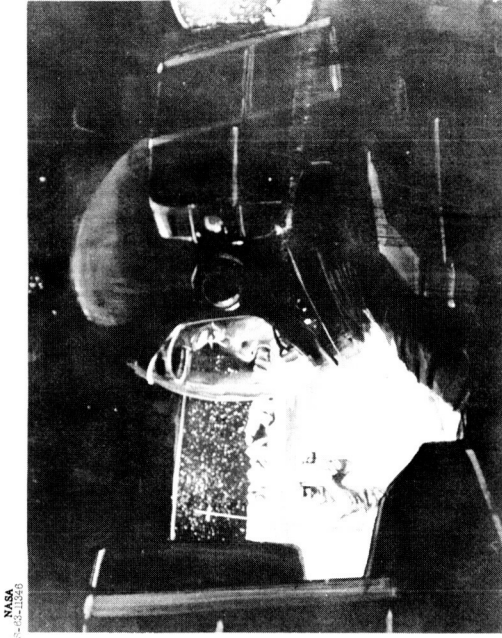


Figure 1-18

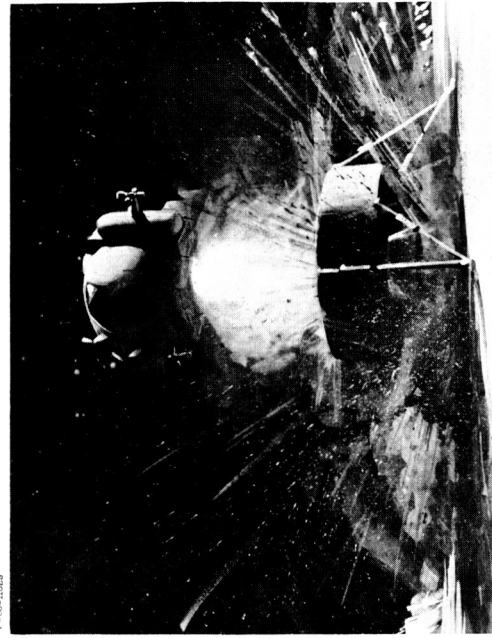


Figure 1-20

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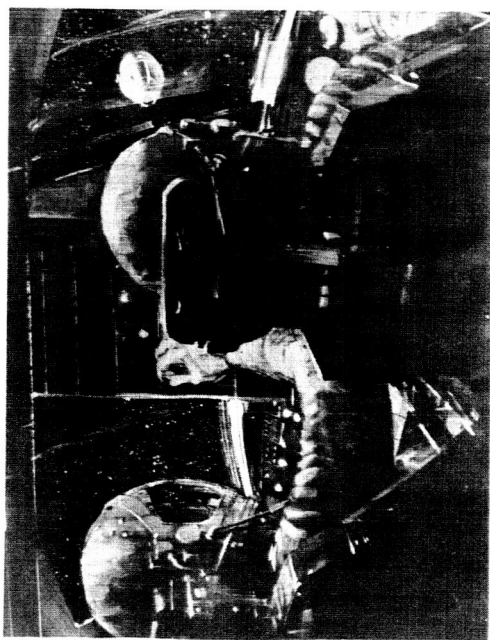


Figure 1-21

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Figure 1-22

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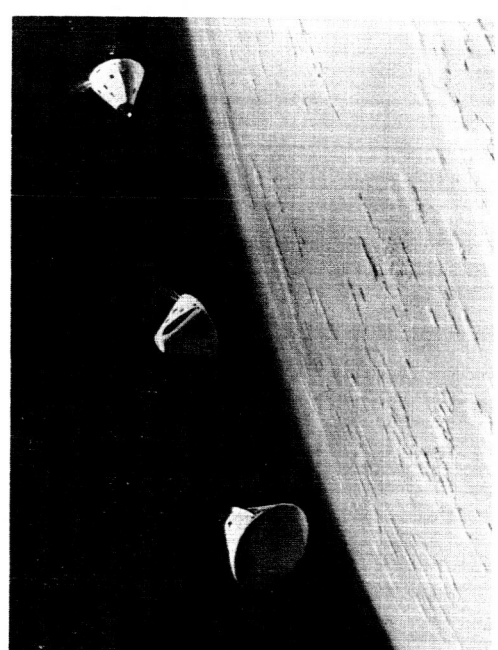


Figure 1-24

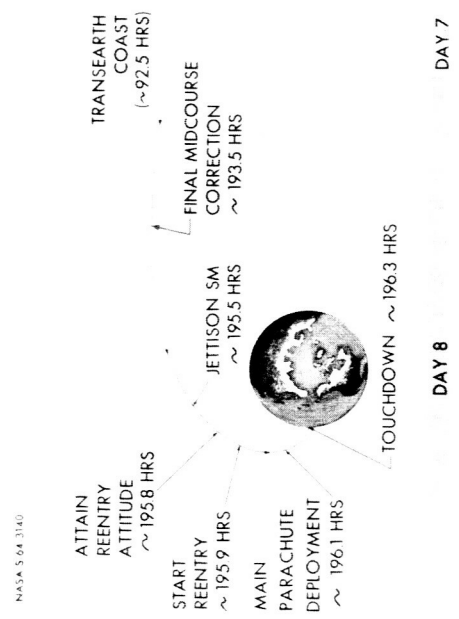


Figure 1-23



Figure 1-25

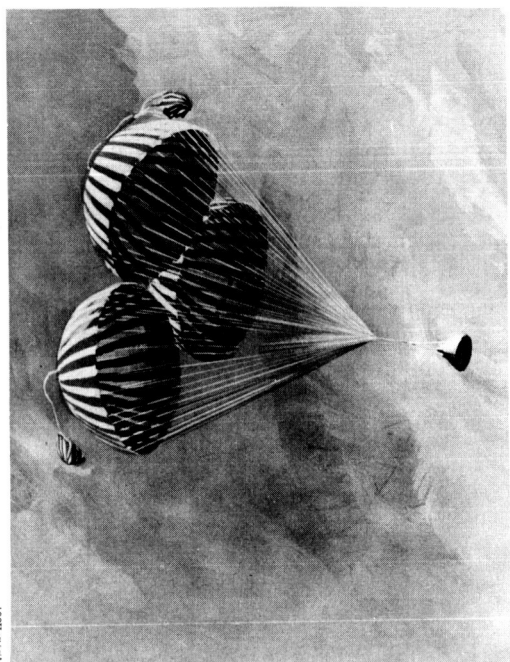


Figure 1-26

2. SPACECRAFT DESCRIPTION

By O. E. Maynard

This paper will limit the description of the spacecraft to a broad description of the modules and will contain details of the operational subsystems. These subsystems may be grouped in twelve areas.

Subsystems	Command module	Service module	Lunar excursion module	
			Ascent stage	Descent stage
Structure	X	X	X	X
Stabilization and Control	X		X	
Navigation and guidance	X	X	X	
Crew provisions	X		X	
Environmental control	X		X	
Landing gear	X			X
Instrumentation	X		X	
Electrical power	X	X	X	X
Propulsion		X	X	X
Reaction control	X	X	X	
Communications	X	X	X	
Controls and displays	X		X	

SPACECRAFT

The spacecraft launch configuration (fig. 1-6) shows the five major parts of the total spacecraft as it is mounted on the top of the instrument unit of the S-IV B stage of the Saturn V launch vehicle.

The launch escape system is provided to abort the command module from the rest of the system during the atmospheric phase of the flight in a manner much like the Mercury system. It is a solid propellant

system of about 150,000 pounds thrust with a 30,000 pounds thrust jettison motor and a 5,000 pounds thrust pitch control motor. It is jettisoned as soon as the aerodynamic loads are such that the service propulsion system can perform the separation function.

The adapter provides the structural attachment for the service module and provides both a shroud for the atmospheric phase of the flight and structural attachment for the lunar excursion module (LEM). It is jettisoned down to the LEM attachment after translunar injection. The design currently folds it back and retains it with the instrument unit.

The command module (CM) is the manned command center for earth launch, general spaceflight activities, earth reentry and recovery. It provides for a crew of three.

The service module (SM) provides certain antennas, the reaction control system for spaceflight attitude control, and the main propulsion system for trajectory control and lunar orbit entry and exit. The service module also houses radiators for thermal control of the spacecraft, hydrogen and oxygen supplies, and fuel cells which generate power and water. The power consumables and coolant fluids are piped through umbilicals to the command module for all phases up to earth reentry, landing and recovery.

The lunar excursion module (LEM) is designed and provided specifically for the lunar landing mission. The LEM provides for a crew of two; its mission includes separation from the CM in lunar orbit, descent to the lunar surface, support for lunar surface exploration, lunar launch and rendezvous with the CM in lunar orbit.

Figure 2-1 shows the spacecraft in the spaceflight configuration as it would be after transposition, docking, and subsequent extraction of the LEM from the adapter. At this stage the LEM landing gear and SM antenna are now deployed.

The SM service propulsion system (SPS) and reaction control system (RCS) provides the necessary propulsion for maneuvers in this configuration. The LEM descent engine, which is also gimballed, and the LEM RCS could provide certain propulsion capability as well.

The LEM normally is essentially passive in this configuration. It is checked out in lunar orbit by the crew who would transfer from the CM through the docked interface into the cabin of the LEM ascent stage. Both cabins are then habitable with open face plates on the space suits.

Attention should be called to the environmental control system radiators on the SM and the severable umbilical between the SM and the CM.

There are two forward viewing windows and two side viewing windows in the CM, and there are two more side viewing windows in the LEM with an additional window in the top of the LEM cabin. Seven windows are provided in this configuration.

Navigation optics are on the opposite side of the CM and on the top of the LEM ascent stage.

Extra-vehicular access/egress is provided in this configuration through either the side hatch on the CM or the forward hatch on the ascent stage of the LEM.

Relative roll orientation is variable but would be planned with normally wide tolerances.

COMMAND MODULE

The command module (CM) is an ablation cooled, honeycomb sandwich, multiple structure which provides crew protection against all environments.

The living area in the CM (fig. 2-2) provides for the three astronauts to be properly supported on shock mounted couches for earth launch, powered spaceflight, earth reentry, landing, and recovery.

The left hand station is termed the flight control station and is very active during launch, abort, reentry, and landing. The right hand station is termed the system management station and is very active at any time in the mission when checkout or malfunction detection equipment is involved. The center station provides access to the critical elements of both flight control and systems management to distribute the tasks and provide suitable redundancy.

The navigation station is provided for spaceflight navigation sightings and a general work area. There is space available under the couches for stowage and a rest station during spaceflight.

Onboard equipments, largely optical, inertial and electronic, are located in the lower equipment bay with a controlled environment as provided by glycol-cooled cold plates. A major portion of the scientific payload will also be in this lower equipment bay. Right and left

hand equipment bays are also provided. The environmental control system provides 100 percent oxygen environment at approximately 5 psi in both the cabin circuit and the suit circuit.

The crew transfer hatch, tunnel, reentry heat protection, and the shock absorbing probe portion of the landing mechanism are shown on the center line. The major equipment outboard of this, and above the bulkhead, are the earth landing system parachutes and mortars. In the lower toroidal bay are located RCS engines and reactants for earth reentry, landing and recovery.

SERVICE MODULE

The service module (SM) in figure 2-3 houses the fuel cells, cryogenic reactants (H_2 and O_2) and radiators for the environmental control system (ECS) and the electrical power system (EPS). The SM supports the CM at six points for earth launch and powered space flight. At three of the points are tension ties. It mounts a high-gain antenna, a radar antenna, and other equipment not essential for earth reentry, landing, and recovery. The configuration is centered around the service propulsion system which uses an ablation cooled engine, burning earth-storable hypergolic propellants, and is fed by an ambient helium pressurization system. There are six longitudinal bays; two bays house long cylindrical oxidizer tanks; two others hold fuel tanks; and the remaining two are used for equipment such as fuel cells and reactants.

There are four sets of reaction control system quadrant assemblies with propellant and four orthogonal reaction control engines on each. These assemblies are complete with propellant and pressurization, giving 16 radiation cooled engines in all. The same engines are used in the LEM ascent stage but are arranged somewhat differently.

The SM external structure is an aluminum honeycomb sandwich. The required meteoroid protection is to be provided by protecting critical components and tanks with local internal shrouds.

LUNAR EXCURSION MODULE

The lunar excursion module (LEM) is illustrated in figure 2-4. The LEM is, of course, the spacecraft from which the manned lunar exploration must be conducted. It is a two-staged spacecraft designed for missions from lunar orbit. It is configured to operate separately

from the CSM for periods up to 48 hours. It is designed for lunar surface operation times of 24 hours with additional contingency times either on the surface or in lunar orbit prior to rendezvous.

The descent stage has an earth-storable propulsion system employing an ablation-cooled engine with a radiation-cooled skirt. It is throttleable (about 10:1) and the engine is gimballed for thrust vector trim control. The system is pressure fed from an ambient helium system. It has four landing legs which are stowed in the adapter retracted and then deployed prior to landing. The inboard gear structure is also used to attach the LEM descent stage to the adapter.

The landing gear is designed to land on slopes similar to those shown in figure 2-5. The gear is also designed to permit landings with up to 10 ft/sec vertical velocity, 5 ft/sec horizontal velocity and random orientation. It is expected that the flight control system will be able to control velocity and orientation well below the model design value, and that the LEM will be able to be launched from the descent stage at angles up to about 30°.

The ascent stage has a fixed thrust, non-gimballed, all ablation cooled, ambient helium pressurized, earth storable, propulsion system; the system employs a single oxidizer tank and a single fuel tank at an O/F ratio of 1.6 to 1.0. The LEM reaction control system employs the same engines as on the SM and is used for attitude control during both descent and ascent; the system has a dual set of positive expulsion tanks.

Reactants and elements of the subsystems which are not required after lunar launch are stowed in the descent stage, and those required for the launch rendezvous and docking are in the ascent stage. The descent stage thus serves the ascent stage in a manner much like the SM services the CM. The major portion of the scientific payload is stored in the landing stage and the payload to be returned to earth is put in the ascent stage cabin.

The CM and LEM dock, and the crew transfers through the top docking interface. Extravehicular and lunar surface egress is provided by the front hatch.

There are forward, upward, and downward viewing windows close to each of the two crew members' eyes. A third window is provided above the left-hand crew member's head to facilitate docking.

The plan view (fig. 2-6) inboard profile of the ascent stage shows two crew members in a stand-up position with their umbilicals going back to the environmental control system. Portable life support systems

(backpacks) have been transferred from the CM and are stowed ready for extravehicular use. The center of gravity is located very close to the engine thrust vector by distributing inert equipment about it and by distributing reactants uniformly as well. The 80 pounds scientific payload to be returned is located close to the center of gravity.

The side view (fig. 2-7) shows the top hatch, front hatch, the two backpacks, scientific payload, optical aligning telescope, inertial measuring unit, rendezvous radar, high gain antenna and omni VHF antenna. The docking drogue is shown above the top hatch at the CM - LEM interface.

The two crew members (fig. 2-8) stand essentially erect at their stations. There is a minimum of encumbrance and they are able to attenuate the landing impact by body flexing with a minimum of constraint.

The left hand crew station is the flight control station and the right hand station is the systems management station. The optical alignment telescope is located at the center line.

Hand flight controls and displays are provided at each station for balanced tasks. The view out each window is exceedingly good as a result of the window placement close to the astronaut's eye position. The docking window is above the left hand crew member's head.

COMMUNICATIONS SYSTEM

The communications links are shown in figure 2-9 for earth, CM, LEM, and extravehicular astronaut (EVA). The earth-spacecraft links are all S-band. The EVA-LEM-CM links are VHF. The command service module (CSM) provides functional capability for voice, television, data transmission, data recording, near earth tracking and deep space tracking.

The LEM provides functional capability for voice, television (from lunar surface only), data transmission (recorded on CSM or earth), and tracking S-band (deep space only).

Figure 10 shows how the communications provides essentially five functional capabilities. Considering CSM first:

(1) Voice is provided CSM-to-earth, EVA-to-CSM-to-earth, CSM-to-LEM and recovery.

(2) Television is provided in CSM flight at 320 lines per frame, 10 frames per second.

(3) Data transmission, at 51,200 bits per second pulse code modulation telemetry system, is utilized to send approximately 350 data samples to the earth. A low bit rate (1,600 bits per sec) made it available for use in the event of a power amplifier failure and for prime power conversion.

(4) For data recording, the CSM can record and play back the CSM telemetry data, both at 1,600 bits/sec and at 51,200 bits/sec; it can also record and play back 1,600 bits/sec data received from LEM and LEM/CSM crew members' voices. (This is a 14 track recorder, 12 tracks are presently in use with a maximum recording speed of 15 inches per sec.)

(5) Tracking is provided by a ground and spacecraft S-band system similar to the L-band system used to track the mariner spacecraft to Venus. During deep space operations, all communications with earth including voice, telemetry, TV, and tracking, is done via the S-band system.

The on-board equipment consists of a phase coherent receiver and transmitter, a 20 watt power amplifier, and a 26 decibel gain antenna.

The LEM communications system is identical to the CSM's with the following exceptions:

(1) There is no recovery voice; however, an EVA can transmit to and receive from either the earth or the CSM through LEM relay.

(2) There is no data recorder on LEM; only voice is recorded and the tapes are returned.

(3) TV is transmitted from the lunar surface only (none in flight) after erection of a 10 ft parabolic antenna. This approach was adopted to reduce ascent stage antenna weight.

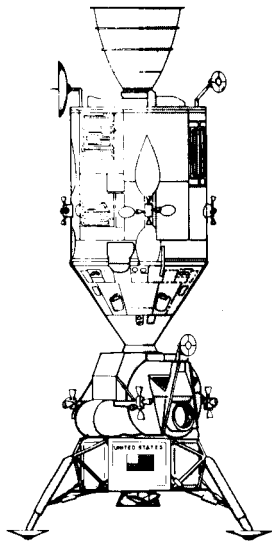


Figure 2-1

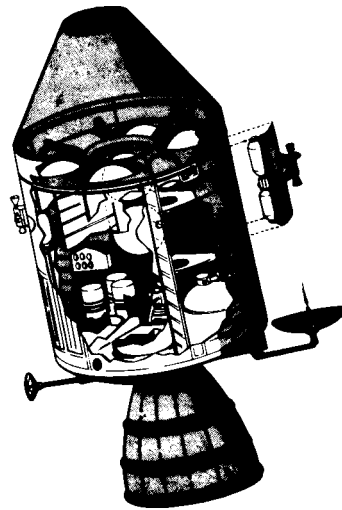


Figure 2-3

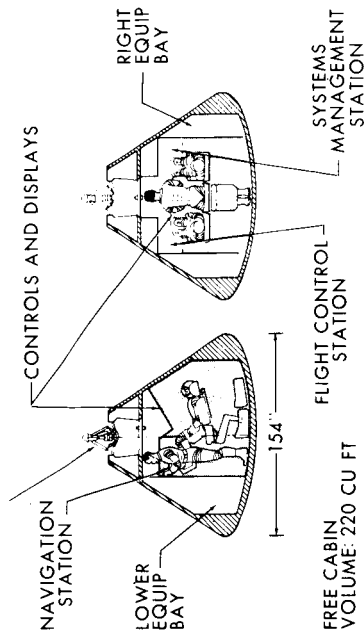


Figure 2-2

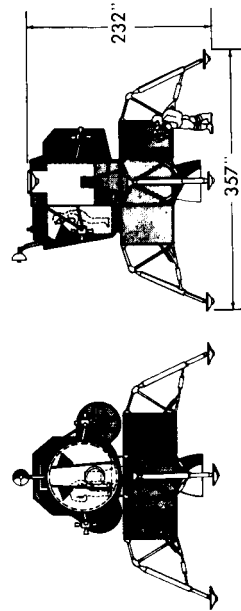
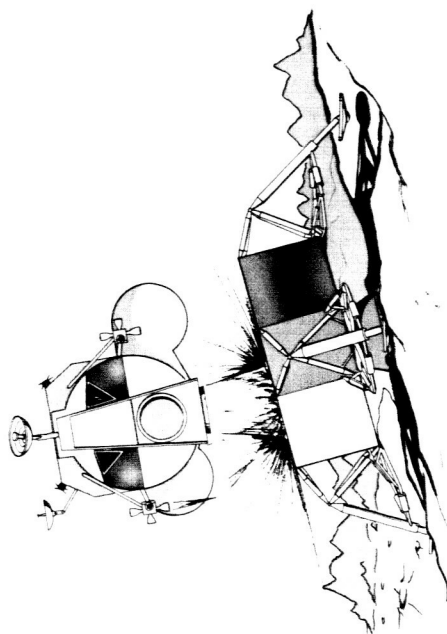


Figure 2-4

NASA S. 64.4046



NASA S. 64.4049

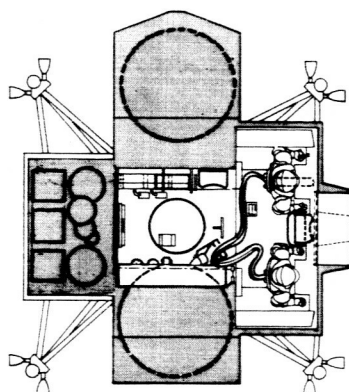


Figure 2-6

NASA S. 64.4045

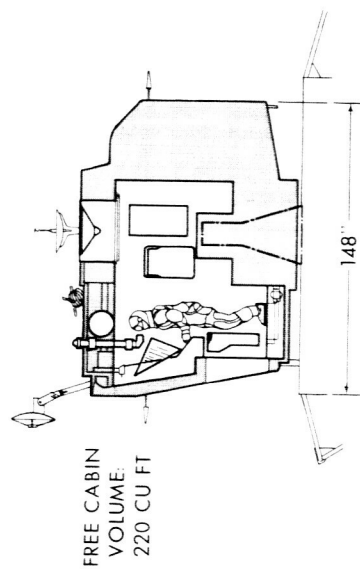


Figure 2-7

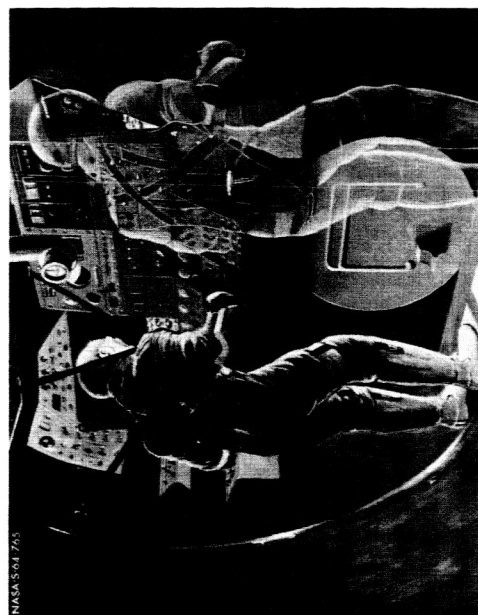


Figure 2-8

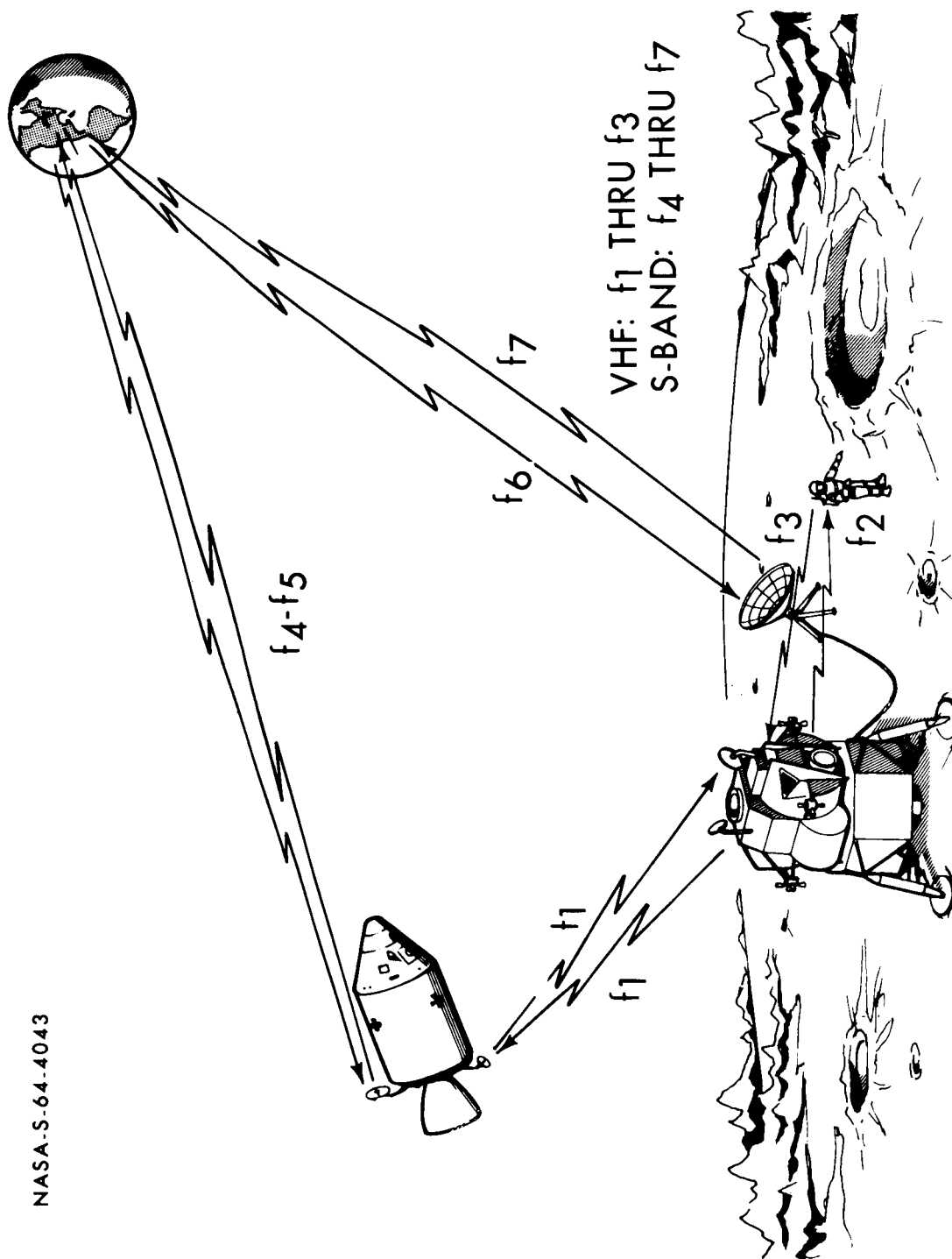


Figure 2-9

3. SPACECRAFT CAPABILITY FOR APOLLO SCIENTIFIC EXPERIMENTS

By John Eggleston

INTRODUCTION

"The ultimate objective of Project Apollo is the landing of men on the moon, observation and limited exploration of the moon in the landing area, and safe return to earth."

"In the design of the vehicle, provisions shall be made for 250 pounds of scientific equipment to the moon and the return to earth of 80 pounds of scientific specimens and data."

These objectives and design criteria from the original Statement of Work for the Apollo spacecraft set the stage in 1961 for the initiation of the Apollo mission and for those experiments which are classed as scientific. The plan for providing the capability in the spacecraft to carry these experiments is the subject of this report. Some of the design considerations for the experiments are also covered.

SPACE AND WEIGHT DISTRIBUTION

Types of Instruments

In order to lay the groundwork for space and weight distribution it is necessary to first understand the three categories of instruments to be carried. First, there are those instruments which the astronauts will actively use only on the lunar surface. These are referred to as active experiments. Examples of these are geology picks, sample containers, coring devices and other hand tools. Secondly, there will be those experiments which the astronaut will set up, check out, put into operation and leave on the surface to operate while he goes about his other duties and which, in most cases, will continue to operate long after he has left the surface for earth return. These experiments are called passive. Examples of these are seismic equipment, meteoroid and ejecta measuring devices, radiation instruments, mass spectrometers, et cetera. Both the passive and active experiments can be and will be carried in the LEM descent stage and removed only on the lunar surface. Finally, there is a third class of instruments which requires separate provisions. These are the instruments which the astronauts must carry in the command module and LEM ascent stage cockpits. In some cases,

such as the cameras and film, these instruments are used during the translunar and transearth phases of the mission for photographic data as well as on the lunar surface. Other equipment such as extra film, tape for the voice recorder, sample containers, et cetera, will be carried back to earth. Only this type of equipment will be carried in the cockpit. All other equipment goes into the LEM descent stage equipment bay.

Weight and Volume

With these three classes of equipment defined, a macroscopic look at the weight and volume distribution in the various modules and stages is given in figure 3-1. Listed across the abscissa of this figure is the weight, volume, power and telemetry available. Listed on the ordinate are the various phases of the mission which apply from earth launch to lunar orbit, during the lunar landing, the lunar launch, and the earth return. As shown in figure 3-1, the command module will be launched with between 40 and 80 pounds stored in that module. The remainder of the 250 pounds of scientific payload will be carried in the LEM descent stage. This will vary between 170 and 210 pounds. To carry this equipment, 3 cu ft is provided in the command module and 15 cu ft in the LEM descent stage. At the present time, there is no power or telemetry available for these experiments in either module.

Once in lunar orbit all 80 pounds of the equipment in the command module can be transferred to the LEM ascent stage. However, 20 pounds may be left in the command module for photographs or experiments from orbit. To accommodate this equipment transfer 3 cu ft is provided in LEM ascent stage. Once on the lunar surface 2,400 watt hours of power will be available for scientific equipment from the LEM ascent stage. This power is primarily in the form of 28 volt direct current. This power will be used primarily for drilling equipment and for any lights required for earth-shine landings. For the passive scientific equipment located in the LEM descent stage self-contained power and telemetry will be provided.

At lunar launch, the LEM ascent stage will be capable of carrying 80 pounds of scientific data or lunar surface samples in 3 cu ft of volume. Once in orbit and rendezvous with the command module is achieved, this 80 pounds may be transferred to the command module for return to earth. Any payload left in the command module during the lunar orbit, such as a camera, must be placed in the LEM ascent stage and left in lunar orbit prior to earth return in order to accommodate only the most valuable 80 pounds of scientific data and samples. Some additional volume will be available in both the LEM ascent stage and command module during the later phases of the mission. Storage compartments which normally carry the disposables such as food and lithium

hydroxide cannisters will provide this space; hence, 3+ cu ft are available in these two modules, as indicated in figure 3-1.

Storage Compartments

In figure 3-2 the scientific equipment storage compartments in the lunar excursion module (LEM) are illustrated. In the ascent stage approximately 3 cu ft is available. At least 2 cu ft of that space is available on the left-hand equipment bay directly behind the crew compartment as illustrated in this figure. The remaining 1 cu ft has not been specifically located at this time. In the LEM descent stage 15 cu ft is available in a compartment on the left rear side of the stage. Actually, this volume is broken up into two compartments. One compartment is for passive scientific experiments, the other compartment for the active experiments. In each compartment the cover is removable, the experiments will be attached to racks which will slide out, the active scientific experiments will be strapped down on these racks, the passive scientific experiments will be attached as modules. It is anticipated that access on the launch pad will be available for these experiments up until eight hours from launch. However, this access will be used sparingly for module replacement in case of failure prior to launch. A mockup of these compartment volumes will be available soon.

The scientific equipment storage compartments in the command module are illustrated in figure 3-3. This figure shows the volume which is available for spacecraft used for early orbital flights. Although the figure shows something over 7 cu ft of volume, it should be emphasized that this volume is available only during the early orbital flight. For the lunar mission only 3 cu ft will be available. This volume has not been designated at this time; however, it will be made compatible in both size and shape with the 3 cu ft of volume in the LEM ascent stage.

This compatibility of volume is the subject of figure 3-4. Listed in this figure are four separate areas required for the items to be transferred between modules. For the sample return containers at least 2.2 cu ft of rectangular volume is required. This compartment must be capable of carrying 80 pounds of weight. The still camera and accessories such as the lens, filters, and handle will take up 0.4 cu ft and will require about 8 pounds. Extra film for this camera and the tape for the LEM recorder will require about 0.1 cu ft and an anticipated weight of 2 pounds. A sequence camera not chargeable to the scientific payload will be carried in a fourth area along with its film and accessories and will require about 0.3 cu ft and will weigh about 8 pounds. Although it may be noted that the sum of these weights exceeds the

80 pounds allowable in the design, it should be emphasized that these compartments must be designed to carry this weight, but that the total weight to be carried will be only 80 pounds.

Sample Containers

Some additional description of the lunar surface sample containers is in order. These containers should be sterilized and designed for pressure differential of 14.7 psi. Prior to the mission, these containers will be sterilized, evacuated, and sealed at MSC. They will be carried to the moon in the LEM ascent stage and carried out on the lunar surface in a sealed condition. On the lunar surface they will be opened and small individual numbered bags, packing material, and portable carrying case will be removed from these containers. The containers will be left open until samples in the individual bags are placed in the container, packing put in for fill, and the container resealed. After sealing, the containers are put back in the LEM ascent stage. Following lunar launch and rendezvous with the command module, these containers are transferred to the command module and are stored there throughout the transearth, earth reentry, and landing phases of the mission. The containers will then be carried to a sample transfer facility and opened in a sterile vacuum chamber here at earth. Although it is obvious that for pressurized containers a cylindrical or spherical shape would be more desirable, spacecraft design considerations indicate that rectangular shapes will provide more optimum storage conditions.

Listed in figures 3-5(a) and 3-5(b) are typical payload breakdowns of the scientific equipment carried on a typical mission. Listed in figure 3-5(a) are both the equipment which is stored in the LEM ascent stage and the active experiments carried in the LEM descent stage. The list indicates that this equipment totals about 100 pounds. Listed in figure 3-5(b) are the typical equipments which would constitute the passive experiments. It should be noted that for a total weight of 150 pounds the power supply and its telemetry are expected to require about 80 pounds of this total weight. For experiments which require power for only one week or so, batteries or fuel cells could be used. However, most experiments will be operated for six months to a year, and for this purpose, radioisotope sources producing about 25 watts will be provided. It may be noted that a telemetry antenna has not been included in this weight since it is expected that telemetry equipment will share the antenna to be used for the operational instruments on the lunar surface. This antenna will be left on the lunar surface when the LEM ascent stage is launched.

SCHEDULES

In the Mercury program experiments were an afterthought in a spacecraft not specifically designed to carry them. In order to use a camera or some instrument in flight, each had to undergo a very rigorous set of tests known as "flight qualification." These tests made certain that the experiment would not explode if the cabin were suddenly depressurized, or would not create an electrical disturbance to the spacecraft instruments, or spark or give off noxious gases, et cetera. Furthermore, since it was necessary to expend a great deal of trouble and expense to fly these instruments, assurance was sought that they would work in the environment to which they would be exposed. To verify this, many so-called proof tests - a set of tests to prove the instrument works after it is subjected to a launch and space environment - were performed. Since Mercury experiments were never very sophisticated, the experiments were allowed to be retrofitted to the spacecraft at the launch area.

This concept changed with the Gemini Program. The White Room concept, where final assembly and checkout of the spacecraft takes place in a very clean room at the manufacturer's plant, was introduced. This concept required that the experiment be approved and fitted, or attached, to the spacecraft at the manufacturer's plant at least a year before the launch date. This has forced some very tight schedules, to which the Gemini experimenters can well testify. As with Mercury, the Gemini spacecraft was not designed with scientific experiments in mind. The success or failure of the mission does not depend on the success or failure of any one experiment. Apollo is different. Experiments are very much a part of the mission, and with this privilege comes the responsibility of seeing that these experiments operate in the lunar environment and that they do not endanger the spacecraft or the life of the astronaut. It is going to take every bit of time from now until the Saturn lifts off at the Cape to achieve this objective. One way of looking at it is that experiment planning is already two to three years behind the spacecraft designers.

In figure 3-6 a schedule is shown for some of the long lead-time experiment hardware such as may be required for the passive experiments. Officially, the first lunar landing mission occurs before the end of the decade. Obviously, experiments have to be prepared to go before that. For this reason, flight qualified hardware should be ready by January 1, 1969. This launch date is purely fictitious; it simply establishes an end point. In order to meet such a launch date, the start-program beginning must be made by June 1964.

During the next six months, breadboard models should be prepared and a go-ahead received from Office of Space Science and Applications

(OSSA) by the end of the calendar year, 1964. The first contractual arrangement will be for a prototype model starting in January 1965. This model will be functional and will provide field tests for scientific evaluation. At this point, all changes such as increasing size of knobs or functional uses required for the astronaut and for the scientific requirements must be made. During the two and one-half months allowed for scientific evaluation, pre-design of a proof-test model will occur. Following the scientific evaluation of the prototype model, the proof-test model will go into fabrication. Final-assembly acceptance tests and environmental tests will be made. A number of proof-test models will be required both for scientific training, for MSC approval and for delivery to the manufacturer to ascertain compatibility with the spacecraft. During the final stages of the environmental tests, the flight model hardware will go into final engineering. Three flight test models will be required. The first of these models will be completely quality tested. The second model will be the primary flight article, the third model will be the backup. The flight and backup models will be delivered to the Cape three months before the anticipated launch date. It should be emphasized that this typical schedule is that required for the more complicated passive scientific equipment. For more simple equipment such as the hand tools, less stringent schedules will be imposed.

DESIGN CRITERIA

In a greatly simplified form, some typical environmental design criteria can be listed. The equipment to be stored in the crew area must be designed to survive temperatures from 40° to 140° F. That equipment stored in the outside must survive temperature ranges from -250° to +200° F. These temperature ranges, of course, exclude the higher temperatures obtained during earth launch and reentry. The vibrational noise and buffet loads will be very high, and specific environments will be given the contractors. The acceleration tests must show that the equipment can survive 6g for 140 seconds. Although the actual acceleration will peak at 6g during earth launch, these design conditions require tests for 140 seconds. For that equipment that must survive the reentry loading, a test condition of 20g for 120 seconds is required. Shock loading for equipment during lunar landing will require 14g tests. For that equipment which must survive earth landing, 78g's is required. In the cockpit of the spacecraft the humidity level of approximately 95 percent with free moisture with about a 5 percent salt content from perspiration must be survived. The cabin atmosphere will be pure oxygen at 5 psi. Detailed design criteria are available and will be given out to the contractors for hardware.

SUMMARY

Some of the principal points made in this talk are listed in review. Both active and passive experiments will be carried in the scientific payload. The passive experiments will be self-contained with power and telemetry. Most equipment will be carried in the LEM descent stage. Provision is being made for that equipment which must be carried in the LEM ascent stage. There will be on-the-pad access to the equipment in the LEM descent stage. Two compartments will be provided in the LEM descent stage. One modular for the active experiments and the other integral for the passive experiments. The command module and the LEM ascent stage compartments will be compatible for transfer of equipment. Provision will be made in the command module for in-flight experiments during earth orbital and build-up flights.

CONCLUSION

What has been given in this presentation is a very quick and general description of the payload provisions. There are at MSC a small, competent group of technical people in the various sciences involved in the Apollo mission. Some of them are teaching the astronauts geology and geosciences. Others are in geochemistry, radiation, meteoroids, lunar atmospheres, geodetics, and cartography. These people are here to help in developing experiments and to provide the technical assistance in getting these experiments onboard the spacecraft. This center has a policy of providing technical monitors for each experiment to be flown in a manned spacecraft. One of these people will be assigned and will follow each particular experiment from concept to completion to data delivery. They will be responsible for seeing that the experiment is ready, that the prototype and proof test equipment is received at MSC for proper training of the astronauts in its use, and that the flight hardware is integrated with the rest of the experiments for flight and properly stored aboard the spacecraft in operating condition.

Studies, breadboard models, and prototypes of many of the potential experiments are already underway both here at MSC and under contract to industry. Funds for these studies come from the Manned Space Sciences Division of the OSSA. The decisions as to which experiments are finally flown rests with the scientific community and several committees within NASA. Regardless of the choice, every attempt will be made to provide the space, weight and training for these experiments within the constraints set by the Apollo Program Office and to provide the technical monitoring of these experiments on an individual and integrated basis.

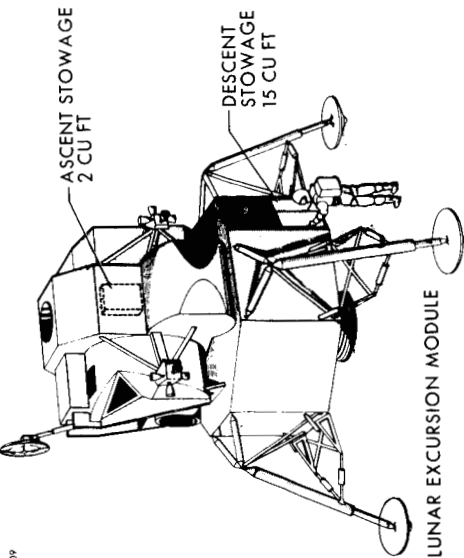


Figure 3-2

NASA S 64-3809

ITEM	VOLUME REQUIRED	VOLUME SHAPE	PAYLOAD WEIGHT
SAMPLE RETURN CONTAINER	2.2 FT ³	RECTANGULAR PARALLELEPIPED	8.0 LBS
STILL CAMERA AND ACCESSORIES (LENS, FILTERS, HANDLE)	10x8 1/2 x 8 1/2 0.4 FT ³	RECTANGULAR PARALLELEPIPED	8.0 LBS
FILM AND TAPE*	5x5x6 0.1 FT ³	RECTANGULAR PARALLELEPIPED	2.0 LBS
SEQUENCE CAMERA** FILM AND ACCES- SORIES	5x7x14.7 0.293 FT ³	RECTANGULAR PARALLELEPIPED	8.0 LBS

*STORAGE AREA MUST BE COLD PLATED
**NOT CHARGED TO SCIENTIFIC PAYLOAD

Figure 3-4

SPACECRAFT MODULE LAUNCH TO LUNAR ORBIT	W, LBS	V, CU FT	POWER, 28V, DC	TELEMETRY
CM	40-80	3.0	0	0
LEM (DS)	170-210	15.0	0	0
LUNAR LANDING	0-20	3.0	0	0
LEM (AS)	60-80	3.0	2400WATT-HRS	0
LEM (DS)	170-210	15.0	0	PASSIVE UNDEFINED
LUNAR LAUNCH	0-20	3.0+	0	0
LEM (AS)	60	3.0+	0	0
LEM (DS)	170	3.0+	0	0
CM	80	3.0+	0	0

TOTAL 250 EARTH POUNDS TO THE MOON
80 EARTH POUNDS RETURNED TO EARTH
() REQUESTED OR PENDING

Figure 3-1

NASA S 64-3810

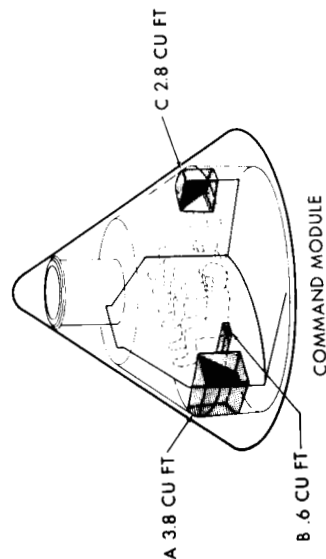


Figure 3-3

	W-LBS
SAMPLE CONTAINER(S)	10
HANDHELD STILL CAMERA	6.6
2 FILM PACKS	0.8
ACCESSORIES (LENS, FILTERS)	0.5
TRIPOD	2.0
GEOLOGY HAND TOOLS	17.6
PHOTOMOSAICS	0.2
CORE DRILL	30
PHOTOHEODOLITE ATTACH	3
HELIOGRAPH	2
THUMPER PLATE (SEISMIC)	4
SOILS MECHANICS EQUIPMENT	6
5 GEOPHONES	2.5
SEISMIC RECORDER	10.0
2000 CABLE	4.0
CRACKERS	0.1
TOTAL	99.8

Figure 3-5(a)

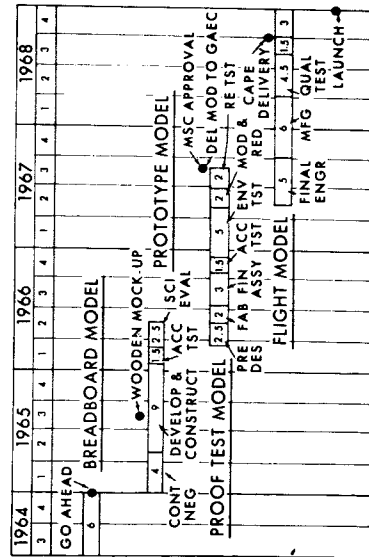


Figure 3-6

	W-LBS
POWER SUPPLY	50
TELEMETRY (W/O ANTENNA)	30
MULTI-AXIS SEISMOMETER	34
MOON TIDE METER	4
PROTON FLUX COUNTER	4
SOLAR WIND INSTRUMENT	3
METEOROID EJECTA INSTRUMENT	12
MAGNETOMETER	9.2
ANCHOR BOLTS	2
THERMAL PROBE & PACKING	2
TOTAL	150.2

EQUIPMENT NOT CHARGED TO SCIENTIFIC PAYLOAD

- MOTION PICTURE OR SEQUENCE CAMERA AND FILM
- TV CAMERA AND ACCESSORIES
- MEDICAL OR BIO-MED PACKAGES

Figure 3-5(b)

4. LUNAR SURFACE ACTIVITIES

By Curtis C. Mason and Elbert A. King, Jr.

INTRODUCTION

Scientists concerned with the exploration of the moon are interested in the actual time spent on the lunar surface, and how it can best be utilized for exploration, collection of samples, and general scientific investigation. There is still some leeway in the exact number of hours that can be spent on the lunar surface. Various authors have assumed a 24-hour stay time on the lunar surface, but with the present systems capabilities of the LEM, it could have a separated life-time of approximately 48 hours. Some contingency time must be allowed for making the rendezvous and docking maneuver in lunar orbit after the ascent stage has left the surface, but this will not be more than a few hours.

TYPICAL 35-HOUR STAY TIME

A typical mission might provide a 35-hour stay time on the lunar surface; however, only a portion of this time is available for scientific exploration. Some of the chief constraints are human factors such as sleep requirements. Some of the constraints now used as ground rules are listed in figure 4-1. If touchdown on the lunar surface occurs at time "0" with launch of the ascent stage 35 hours later, it is likely that the time spent on the lunar surface might be utilized in a manner similar to that shown in figure 4-1.

The first approximately 90 minutes may be spent in LEM checkout. It is most important from a systems and personnel safety viewpoint to find out whether or not the LEM has been damaged in landing, and whether the ascent stage can be launched with a nominal checkout sequence.

Large periods of time on the lunar surface must be devoted to sleep, approximately $15\frac{1}{2}$ hours. It is unfortunate that so much of the time on the lunar surface must be spent sleeping, but if the constraints listed in figure 4-1 are to be followed, this amount of sleep time is required.

Following the current set of constraints, a 35-hour lunar surface stay time allows for four excursions on the lunar surface of 3 hours each, a total of 12 man-hours. The length of the individual excursions is controlled chiefly by the lifetime of the personnel life support system (PLSS) or "backpack." These units now have a lifetime of 4 hours, but one hour is allowed as a contingency factor. The time spacing of the excursions is partially regulated by the recharge time of the PLSS units; 6 hours are required to fully recharge one backpack and only one backpack can be recharged at a time.

Other short periods of time in the lunar stay time period (fig. 4-1) are allotted to status briefs, data analysis, and systems checkout prior to launch. During these periods the astronauts on the moon would exchange essential information with the mission control center at MSC and advise the control center of the status of the LEM and the astronauts.

Immediately after touchdown on the lunar surface and the checkout of the LEM, prior to the first excursion, the astronauts might describe the exhaust effects on the surface by the retro-rocket in the descent stage. This description could include the size and density of particles thrown up by the exhaust, whether or not any of this material actually stuck to the LEM, how far ejecta were thrown, and how long these effects persisted. The area visible from the LEM windows, approximately 180°, should be photographed, landmarks noted and recorded, and the astronauts should attempt to determine exactly where on the lunar surface they have landed. This may be a considerable problem, but it is hoped by the time of a manned lunar landing, photomosaics of the landing site will be available on which the astronauts can locate themselves. The astronauts will also make such changes in their exploration plans as are dictated by local topography, geology, or other landing site conditions as visible from the LEM.

A POSSIBLE TYPICAL MISSION ON LUNAR SURFACE

With the egress of the first astronaut, the first excursion will begin. The first few minutes on the surface will be spent in determining the nature of the surface and how well the astronaut will be able to move about on it. The astronaut will inspect the LEM to see if it has been damaged in landing. The field of view of the LEM is indicated by the area to the right of the vertical line in figure 4-2. At this time, it is presumed that almost all of the activities of the astronaut on the surface outside the LEM will be confined to this area.

First Excursion

At the beginning of the first excursion, the astronaut will take the exploration equipment from the LEM storage bays which have outside hatches. The television camera will be removed from its storage position, the telemetry antenna set up, and the astronaut will pan the lunar horizon and surface. He may focus on any features of interest with the TV camera for real-time transmission to the mission control center. The TV camera could then be placed in a bracket on a leg of the LEM in proper orientation to monitor the area to be covered by the first traverse. There is no requirement for the astronaut to transport a TV camera with him on the traverse.

Taking the hand tools that he previously removed from the equipment bays, the astronaut would then begin the first traverse (fig. 4-2). Along this traverse the astronaut will collect samples, record sample orientation, and record geologic position and selenographic position of samples taken. He will take photographs of features of scientific interest. Perhaps he will deploy geophones at regular intervals in order to conduct a seismic experiment by striking the ground as a source of seismic energy or possibly deploy very small explosive squibs for later explosion. If geophones are deployed and a seismic experiment is conducted, the astronaut should make the first leg of the traverse in as straight a line as possible, assisted in his direction by the astronaut in the LEM. The straight leg of the traverse might be continued until the astronaut is approximately 1,000 feet from the LEM, at which point it might be desirable to make angular measurements on landmarks for triangulation purposed to more accurately locate the LEM on the surface. Such measurements might be made on both traverses, I and II, as well as near the LEM. The route followed back to the LEM should be irregular, taking advantage of the topography and the best sample-collecting areas.

The return part of the traverse should be primarily for the purpose of collecting samples, observing lunar surface structure, taking photographs, et cetera, and should be in the approximate position indicated in figure 4-2. The astronaut who has been on the surface for the first excursion will ingress into the LEM and exchange places with the man who has remained in the LEM during the first excursion.

Second Excursion

The egress of the second astronaut will begin the second excursion. This man will go to the equipment bays and remove the instrument packages and deploy these packages. These packages will have to be connected to the telemetry antenna or provide their own antenna and power supply.

These will mostly be passive packages containing such instruments as radiation monitors, seismometers, and other instruments that are designed to function in the lunar environment long after the astronauts have left the surface. The astronaut should change the orientation of the monitoring TV camera to cover the area of the second traverse, and begin the second traverse performing the same tasks as on traverse I, with the first leg at approximately 90° to the line of the first leg of traverse I. After return to the LEM from the second excursion, the first sleep period will begin. At this time both astronauts will have had consecutive three-hour excursions on the lunar surface.

Third Excursion

During the sleep cycle, the mission control center can monitor the telemetry from the instrument packages emplaced by the astronaut on the second excursion to see that they are performing correctly. At the end of the sleep cycle, the third excursion begins with the egress of the astronaut, changing the orientation of the monitoring TV camera to cover the area of the traverse, and beginning the third traverse into the area between the first and second traverses. The purpose of this traverse (fig. 4-2) would be the geologic and physiographic description of the area covered, collection of samples, and photography of interesting features. With the conclusion of the third traverse, the astronauts should have completed a comprehensive geologic field investigation of most of the area easily visible from the LEM windows within 1,000 feet of the LEM. The astronaut will return to the LEM after three hours and exchange places with the other astronaut.

Fourth Excursion

Excursion IV might be to some nearby feature of special interest such as a small crater, volcanic cone, rock outcrop, large pieces of ejecta, et cetera. This feature may, or may not, be in part of the area previously explored. On this excursion the astronaut would describe, photograph, and sample the feature in great detail. Upon the astronaut's return to the vicinity of the LEM, he should move the instrument telemetry antenna to a location far enough from the LEM so that the rocket exhaust during launch of the ascent stage will not affect its operation. The astronaut would then ingress into the LEM taking with him the encapsulated samples and film packs from the camera, and stow these in the space provided. The ascent stage would then be checked out for launch.

EXPLORATION TRAVERSE EQUIPMENT

To help the astronauts accomplish all of their tasks of scientific investigation on the lunar surface, they must have available a number of small instruments and tools. Some of the equipment that might be desirable is listed in figure 4-3. The pressure-suited astronaut illustrated in figure 4-3 will also be wearing a thermal garment over the top of the pressure suit, and it is obvious that his mobility and dexterity will be rather limited. The 12 items of equipment listed as desirable for the astronaut to carry on exploration traverses would further hamper the mobility of the astronaut. Every effort must be made to combine various tools and equipment, or design them in such a way that they interfere with the movements of the astronaut as little as possible. The items listed, if each were carried separately, would be a cumbersome load for a man without a pressure suit. Redesign of almost all of this equipment will be required.

Geological Instruments

A normal geologist's hand lens that is commonly used here on earth would not be suitable for the astronaut to handle with his limited dexterity, and the focal length is too short to be used through a face plate on a pressure suit helmet. The hand lens to be used on the moon should have a larger field of view than its terrestrial counterpart. A geologist's pick would have to be used with great care to avoid damage to the pressure suit. High velocity rock chips or steel splinters could be very hazardous, unless the pick were employed in a most judicious manner. Some of the astronauts have already sustained minor wounds from flying rock chips on field trips in the geology training course. The reduced gravity and very thin atmosphere of the moon would greatly increase this hazard. A hand-coring device will be under development very soon. This will enable the astronaut to take short cores from consolidated rock material in a few minutes, and will have the advantage of providing a sample in a predictable shape, thus making the sample encapsulation more efficient.

Surveying Instruments

A small surveying instrument of some sort may be necessary to record sample orientation and general attitude of geologic units on the lunar surface. On earth a Brunton compass serves this purpose, but this instrument relies on a strong magnetic field of known orientation. This type of instrument is not suitable for use on the moon because the magnetic field, if present, is very weak and of unknown orientation.

A small shadow compass or gyro compass might perform this function reliably. A Jacob's staff would aid the astronaut in maintaining his balance, as has been demonstrated in some of the $\frac{1}{6}g$ trajectory flights.

This staff could also be striped for stadia measurements, and photographs taken of the astronaut on the surface by the astronaut in the LEM would yield quantitative information on the distance to the astronaut. This information would be very useful in determining the absolute and relative positions at which samples were collected or important observations were made.

Recording Instruments

A scribe might be useful in recording the sample orientation, and of course, the camera would also aid in this area. The camera is particularly important to earthbound scientists in documenting observations by the means of the best possible photography. Good photographs of the texture, geology, and general character of the lunar surface for all scales are of great importance and should be a routine part of any lunar mission as should be the collection of samples. Present films are probably not suitable for lunar photography, and this area may require considerable development.

Aids to Communication, Navigation, and Cartography

If the astronaut on the surface decides to descend into a small crater, or in some other way to get out of line of sight contact with the LEM, he will place a small reflector so that voice communications can be maintained. This reflector can be carried in a collapsed form and erected when needed. A phototheodolite might prove very useful in locating the LEM on the lunar surface and in determining the exact librations of the moon. This instrument could also aid in establishing higher order reference points on the lunar surface for use in circum-lunar navigation or exact cartography. Some light source will be needed for the astronaut to take photographs in shadowed areas. A small reflector could serve this purpose for small shadowed areas, but larger areas would require a small portable light. A striker plate might be used for coupling seismic energy with the surface, or this function could be performed by small explosive squibs. These would be used in connection with active seismic experiments. The geophones and cable required can be reduced in weight and volume and made quite easily portable. However, this total load of tools and equipment is obviously a great deal for an astronaut to carry. Some means may have to be devised for the astronaut to carry or transport this equipment, and doubtless, much of it can be combined to make the total number of individual items much less.

SELECTED PROBLEM AREAS

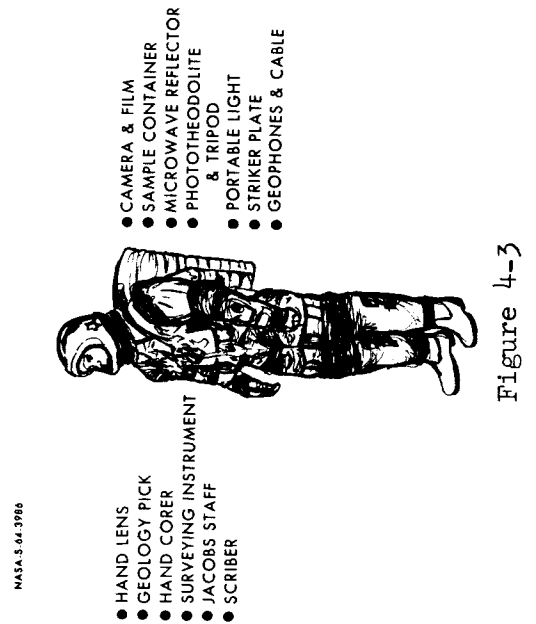
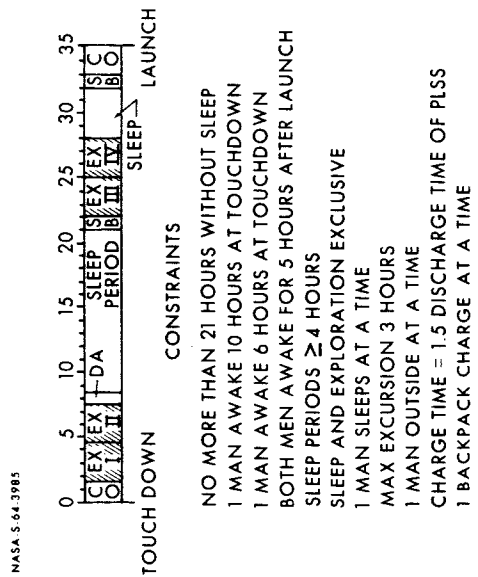
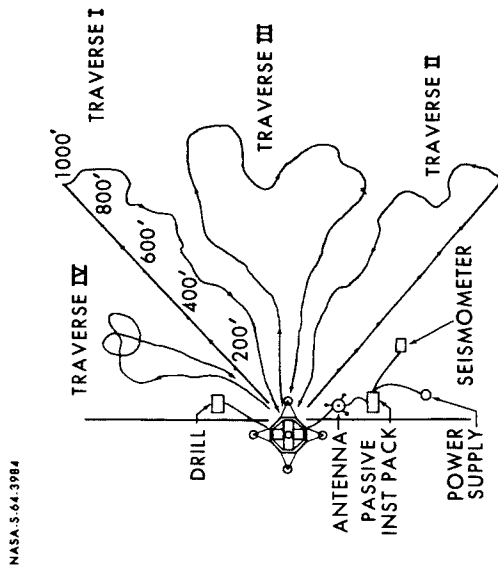
Sample Collection

Each of the aforementioned items of equipment has many problems associated with it, but this paper will briefly discuss only two of these areas. The collection of samples is one of the most important, if not the most important, function of the astronaut on the lunar surface. The astronauts should be well prepared for this task by participation in the geology training course which has already been in progress for several months. The limited dexterity and mobility of the astronaut will severely limit the number and kinds of samples he can collect, as well as restrict the manner in which the samples can be packaged. Sample encapsulation and sample contamination are two problems that are closely linked. The techniques for the collection and encapsulation of lunar samples have not yet been worked out, and deserve a great amount of effort. Contamination of the samples by organic or inorganic earth materials must be avoided. Contamination of individual lunar samples with other lunar materials should be minimized also, especially in the case of "clean" outcrop samples. The environments in which the samples might be stored, and the materials to which the samples might be exposed, must be precisely controlled and recorded. Standard sample collection equipment is mostly not suitable for the collection of lunar samples, and much effort must be made to develop equipment suitable for this task. A great deal of information could be lost from lunar samples by improper handling, collecting, or packaging.

Photography on Lunar Surface

Photography on the lunar surface also presents a number of difficult problems. The contrast is likely to be very high between areas illuminated by sunlight and the inky black shadows. This problem is much more acute than on the earth because there is a lack of dense atmosphere to diffuse light into shadows. Very high quality photography will, of course, be desired. The film should have minute grain size and great sensitivity, but also be relatively unaffected by the high radiation background. Special films will have to be developed for this purpose. The camera must be very versatile and provide for taking very short range close-ups as well as horizon panoramas. Stereo pairs may also be required for some investigations. It is obvious that high quality photography on the lunar surface presents serious problems in many areas that are very simple on earth.

Of necessity, this has been a very abbreviated sketch of possible lunar surface activities. The Lunar Surface Technology Branch has compiled reference mission activities in great detail, and will soon be documenting astronaut capabilities in field areas in pressure suits. These studies will allow reasonable estimates of the amount of scientific work that the astronauts can perform on the lunar surface, and are likely to reveal additional problem areas. Increased LEM systems capabilities, changes in constraints, or changes in the overall mission profile may allow additional time for scientific investigation on a single mission. Certainly, as knowledge of the lunar surface increases, better plans can be made for exact tasks of scientific exploration on the lunar surface.



5. SPACESUIT CAPABILITIES

By Edward Hays

The Mercury spacesuit was intended to be an intervehicular spacesuit to serve primarily as backup to the cabin pressure of the spacecraft. The function of this suit was rather limited: the astronaut was in the couch; he didn't need to move from the couch; he had only to perform those tasks necessary for returning the spacecraft to earth should a cabin decompression occur.

With the advent of the Apollo lunar excursion program, however, it became apparent that the spacesuit must now meet a multiplicity of requirements. Probably the most important of its new functions is to provide pressurized mobility. A major question to be answered is what kind of work a pressure-suited astronaut can accomplish.

The suit, as presently configured, consists of a pressure garment assembly containing a habitable atmosphere that is 100 percent oxygen at a nominal operating pressure of 3.7 pounds per square foot, absolute. The other half of the spacesuit assembly is a portable life support system. This system contains a breathing oxygen supply, the thermal control, the module for carbon dioxide control, and the telemetry and communication system. There is a built-in power supply along with heat exchangers, water separators, fans, and similar end-devices that present no little packaging and technology problems.

Some of the $\frac{1}{6}g$ flight tests being conducted in coordination with the Department of Defense are illustrated in a technical film listed in reference 1.

As experimental development of the spacesuit progresses, there is an attempt being made to quantitate dexterity and mobility. It is hoped that the scientific community will aid the developmental program by making known to MSC their specific requirements for spacesuit performance during experimental tasks.

REFERENCE

1. Prototype Apollo Suit Mobility Test, Simulated Lunar Gravity. MSC Technical Film no. 213.

6. ASTRONAUT TRAINING

By Neil A. Armstrong

GENERAL TRAINING

Academic Training

General training for the flight crews preparing for the Apollo Mission begins with an academic program designed to compliment or improve the pilot's technical knowledge of space flight. The courses include such subjects as the following: geology, astronomy, physics of the upper atmosphere and space, flight mechanics, digital computers, guidance and navigation, spacecraft onboard computers, medical aspects of space flight, rocket propulsion systems, aerodynamics, communications, and meteorology.

It is obvious that the courses are space mission oriented. For example, the complete mission navigational tasks from lunar insertion to earth entry require a knowledge of 8 of the 12 items listed. In addition to increasing the probability of mission success, these courses will provide competent observers in such non-operational disciplines as the geosciences. These aspects are covered comprehensively with lectures, laboratory periods, and field trips scheduled in six separate series that will continue from the present until completion of the lunar missions.

Environmental Familiarization

The next phase of general training covers environmental familiarization and contingency aspects of the Apollo mission.

The acceleration programs as provided on the NASA and Navy centrifuges (fig. 6-1, 6-2), will provide evaluation of spacecraft systems such as control, displays, pressure suits, and restraints during launch and entry acceleration under normal and emergency conditions.

The effects of vibration on crew members will be studied where applicable. The noise environment will be simulated in the Apollo Mission Simulator.

Training pressure suits are provided for the flight crew to gain experience in donning and doffing the suits, walking at various degrees

of pressurization, mobility in spacecraft mock-ups and mission simulators, and operations under design conditions in altitude chambers.

Similar training will be provided for operational familiarization with the portable life support systems.

Flight crews will participate in altitude chamber-spacecraft tests and checkout. Weightlessness and lunar gravity training will continue through the use of the inclined platform and aircraft trajectory techniques.

Survival Training

The three basic survival conditions, for which training is required, are for tropic (fig. 6-3), desert, and water landings. This training is supported through Air Force and Navy survival schools. Training for all aspects of water recovery will be accomplished in a flotation tank and in open water.

Another aspect of general training is that of astronaut participation in the engineering development of the launch vehicles, the spacecraft, and their various subsystems. This is accomplished through participation in design reviews, engineering simulations, spacecraft and launch vehicle development tests, and through individual engineering assignments. Each astronaut is assigned to participate in and follow through various engineering developmental aspects of the program. This participation provides a means of maintaining individual and group knowledge as well as providing crew contributions to the program development.

Operational Training

Operational training will be conducted with a variety of fixed-base and free-flight simulators. A major portion of the training will be conducted on full-mission simulators that will have the capability of simulating Apollo missions from launch to landings. These simulators will familiarize the flight crew with the over-all mission timing and specific tasks as determined from mission plans.

For the landing and docking maneuvers, which cannot be adequately simulated by static devices, moving-base and free-flight simulators will be provided.

Specific mission preparation (fig. 6-4) begins approximately six months prior to the scheduled flight date and consists of operational

checks in the white room, vacuum chamber, vertical assembly tower, and on the launch complex. This program will require a part or all of the crew for participation or observation. Also, during this period, the crew will utilize the mission simulator to practice normal and emergency procedures, guidance and navigation, control mode switching and tasks, and flight plan and mission rule refinements. In the final stages of preparation, integrated network simulations are conducted with all the world-wide ground stations and flight crews participating.

Concurrent with all other commitments, the pilots must maintain flight proficiency in high performance aircraft and helicopters.

TRAINING EQUIPMENT

Mission Simulators

Two Apollo mission simulators (fig. 6-4) will be provided; one to be located at Houston and the other at Cape Kennedy. Each will simulate the command module (CM) separately or the command and service module (CSM) combination. The internal arrangement of the command module is an exact duplicate of the particular spacecraft being simulated. The controls, displays, and window scenes will be active, and will be driven closed-loop by peripheral computing equipment. The instructor's console will contain duplicate displays and malfunction insertion units.

Apollo Part-task Trainer

The Apollo part-task trainer will be similar to, but less sophisticated than, the mission simulator. It is required to alleviate the workload on the mission simulator and to provide transition training from one flight to the next.

LEM Simulation Equipment

A contract has not been awarded for the LEM simulation equipment; however, its functions will necessarily parallel those of the CSM simulator.

The lunar landing research vehicle (fig. 6-5) will provide piloted, free-flight simulation on earth. It can simulate LEM trajectories and handling qualities for the final 4,000 feet of approach. The gimballed jet engine will provide lift for $\frac{5}{6}$ of the vehicle weight, and effectively

provide a lunar gravity potential. The pilot controls hydrogen-peroxide rockets to provide the descent or ascent accelerations. Additional control rockets, mounted as on the LEM, will produce variable thrust to match LEM angular accelerations and handling qualities.

Gemini Translation and Docking Simulator

In order to provide a realistic, full-scale close proximity docking simulation, the Gemini translation and docking trainer (fig. 6-6) will be modified to accept either Gemini or Apollo modules. This equipment is mechanized, closed loop, through an analog computer. Rotation and translation motions are duplicated by use of gimbals and air-bearing rails.

TRAINING DERIVED FROM GEMINI PROGRAM

Past experience has indicated that there is no substitute for the experience gained under actual operational conditions. The Gemini missions should, therefore, serve as a proving ground and training program for many segments of the Apollo mission. For the actual rendezvous, the digital computers and radar will be operated. In addition, optical, semi-optical, and manual methods will be evaluated. After docking, maneuvers will be accomplished for altering the orbit.

Since both the Gemini and Apollo spacecraft are lifting bodies during atmospheric flight, the techniques of lift-vector control during entry to arrive at a preselected landing point can be evaluated.

The aero-medical functions of the long duration flights will assess the effects of zero-g, required inflight exercises, and sanitation methods and procedures.

Many of the Gemini systems that are similar to those of the Apollo spacecraft can be evaluated under actual operational conditions. These consist of cryogenic electrical systems, onboard computers, inertial platforms, translational propulsive systems, et cetera.

As a result of the Gemini flights, the crews should obtain the important factor of confidence that will assure them that they can perform similar tasks required for the Apollo mission.

NASA S 64-842

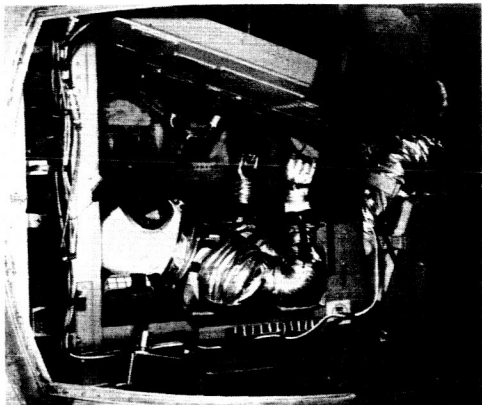


Figure 6-2

NASA S 64-840

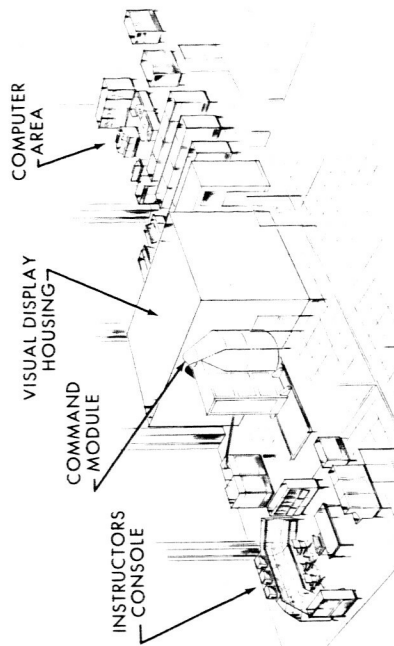


Figure 6-4

NASA S 64-730

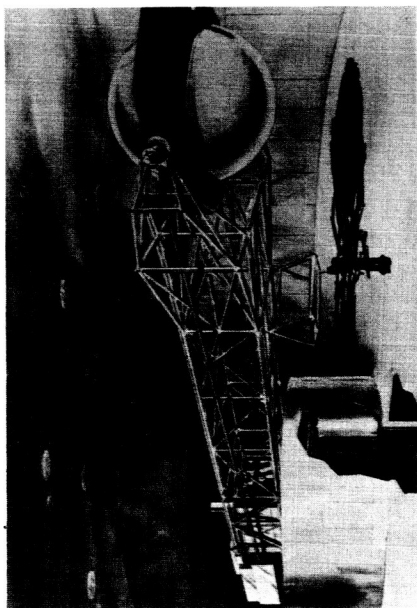


Figure 6-1

NASA S 64-736



Figure 6-3

NASA S-64-018

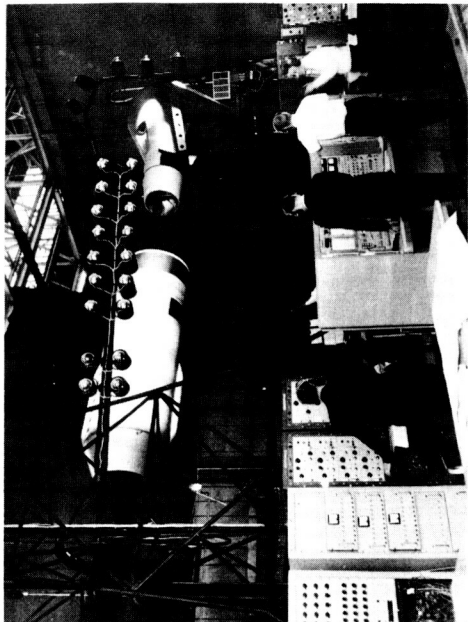


Figure 6-6

NASA S-64-856

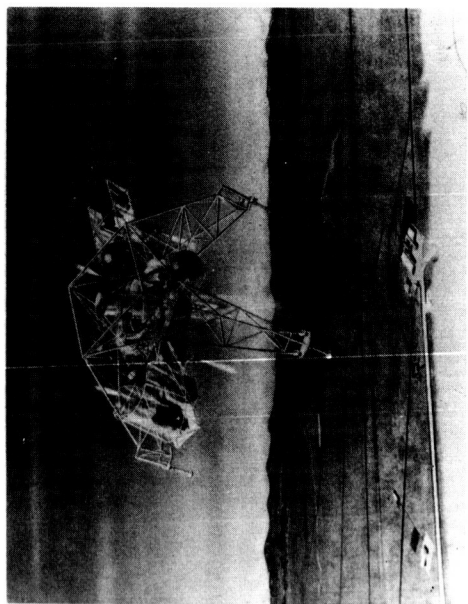


Figure 6-5

7. ASTRONAUT TRAINING IN GEOSCIENCES

By Dr. Ted H. Foss

The astronaut training program consists of six or more training series. The first of these, Training Series I, has just been completed. Outlines of the course are available from the speaker upon request.

Training Series I has been given in several parts. First, there has been a series of lectures entitled "Principles of Terrestrial and Lunar Geology" given by geologists of the U.S. Geological Survey under contract to NASA. These lectures have stressed geologic principles, especially those which apply to both the earth and moon. The principles course has consisted of approximately 30 hours of lectures.

A second series of lectures and laboratory sessions entitled "An Introduction to Mineralogy and Petrology" has been given by geologists of the Lunar Surface Technology Branch of Manned Spacecraft Center. These lectures and laboratory sessions have dealt with hand specimen identification of minerals and rocks, with particular emphasis on igneous rocks and their origin. The mineralogy and petrology course has consisted of about 28 hours of combined lectures and laboratory sessions.

A third part of Training Series I was four field trips which were run as a joint instructional effort by geologists from both courses and were keyed to material given in the principles course.

The first trip was to the Grand Canyon for two days. This trip illustrated the superposition of stratified rocks, unconformities, small scale features of sedimentary rocks, and regional metamorphic rocks (fig. 7-1, 7-2).

The second field trip was to the Big Bend-Marathon region of West Texas for two days. This trip illustrated structures in deformed sedimentary rocks and recent volcanic rocks. During this trip the astronauts had a chance to map geology on aerial photographs (fig. 7-3).

The third trip was to the Kitt Peak Observatory and to the Flagstaff area for two days. This trip illustrated techniques of lunar geologic mapping on 1:1,000,000 IAC charts using telescopic observation of the lunar surface. In the Flagstaff area, the astronauts were flown over several types of craters, and examined some very recent volcanic features on the ground (fig. 7-4, 7-5).

The last trip was to Philmont Ranch in northern New Mexico. There the astronauts were instructed in many standard geological and geophysical techniques, such as section measuring, mapping on a topographic base, correlation of described sections, and seismic, magnetic, and gravity measurements (fig. 7-6, 7-7).

Five more training series which will continue through the Apollo program have been tentatively laid out. These lecture series will go into detail on such subjects as volcanic geology, impact geology, sample techniques, instruction in use of analytical and sampling instruments as they are developed, advanced field techniques, simulated mission profiles, et cetera. Many of these lectures will be given by guest speakers. The lectures in all of these series will be complemented by field trips to appropriate areas.

During Training Series I, it was discovered that the astronauts have exceptional aptitudes and academic backgrounds to become students in the geosciences. Their strong previous training plus their great motivation have resulted in a very rapid rate of learning to a point where the students are actively and ably arguing questions of geologic fact and philosophy with their instructors. It is evident that with further training, the astronauts will be able to function as highly competent observers on the early lunar landings.

NASA
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Figure 7-1

NASA
A-1000-10



Figure 7-2

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A-1000-10



Figure 7-3

NASA
A-1000-10



Figure 7-4

504-16358



Figure 7-6

504-24306



Figure 7-5

NASA
SP-100-10000



Figure 7-7

8. MSC RESEARCH ON LUNAR SURFACE EXPERIMENTS

By John E. Dornbach

INTRODUCTION

The primary scientific objective of the current Apollo program has been defined by Manned Space Sciences Division of the Office of Space Sciences and Applications (OSSA) as acquisition of comprehensive data about the moon. This is to include not only the gathering of scientific data for determining the origin, evolution, and morphology of the earth-moon and the solar systems, but also the accumulation of data and measurements which will directly add to the probability of success of subsequent missions to the moon. This information would largely concern engineering properties of the lunar surface and probable hazards to men and equipment on the lunar surface. The data gathered by the Apollo program would not be mutually exclusive of either scientific or operational analysis. The program is to be guided by the following two major requirements.

First, all facets of MSC operational missions must be supported by information on the earth environment, cislunar space, and the moon.

Second, there must be a response to the lunar surface scientific program for Apollo, such as has been established in the Sonett Committee and National Academy of Science Iowa Summer Study Scientific Guidelines forwarded to Manned Spacecraft Center from OSSA.

In order to establish programs to support the lunar surface mission, many assumptions were made and many questions asked. Some of these questions follow:

How can the astronauts' time be most effectively utilized on the lunar surface?

How will lunar surface contingencies affect the scientific mission?

How accurately will the LEM be able to land near a point of scientific interest?

What is maximum exploration radius of action from the LEM?

How will environmental systems and rest or sleep cycles affect total mission time on the lunar surface?

How will information and samples returned from the first mission affect all experiments and instruments being developed?

Finally, when will the precise payloads and experiments to be carried on each mission be determined?

This last point is of extreme importance to MSC. Because the manned system has developed a high reliability, it can be assumed that there will be little duplication in scientific payloads. It can also be assumed that when specific measurements are made, each succeeding flight will make more precise and more thorough measurements. To gain maximum lead time, instrument development must begin two to three years in advance of the first mission; yet, even though the findings of the first mission may appreciably affect the mission plan for the second, the second mission is expected to follow in no more than three to six months. Due to the extreme value of each minute spent on the lunar surface and the months involved in crew training, it will be necessary to formulate as far into the future as possible the experiments which might be carried on a flight-by-flight basis.

PLANNING STUDIES

Determination of Optimum Measurements, Experiments, and Geologic Studies to be Made on the Lunar Surface

Almost two years ago, a contracted study began which could provide tentative answers to some of these questions. This study, entitled "Determination of Optimum Measurements, Experiments, and Geologic Studies to be Made on the Lunar Surface," has the following aims:

(1) To provide a basis for proceeding with spacecraft interface requirements and for supporting studies on experiments until payloads can be specified.

(2) To provide tentative answers to these questions:

(a) What scientific experiments can be performed on the lunar surface?

(b) How can maximum use be made of the limited time available on the lunar surface?

(c) What combination of experiments would provide a basis for the most comprehensive, systematic analysis?

(d) To what extent will each mission contribute sequentially to the accumulation of knowledge in various scientific disciplines?

Although this study was planned to specify tentative flight payloads, the ultimate Apollo payloads would include inputs from the scientific community and more specifically, from the Office of Manned Space Flight, the Office of Space Sciences and Applications, The National Academy of Sciences, and others (fig. 8-1).

Several steps were required to formulate guidelines to be used in planning for spacecraft design, and for the environment and interface control documentation required for instrumentation for lunar surface experiments. Each study group independently evaluates its area of interest in relation to the weighting factors. These evaluations are then combined on the basis of the primary scientific objectives of Apollo, to determine optimum payloads for the first and succeeding missions. Since the amount of time for a lunar surface mission cannot be stated precisely at this time, there must be some latitude in planning. The second and succeeding missions may become further complicated by the results of the preceding mission. These findings may seriously affect the payloads that might be planned and the training which the astronauts might receive.

In Phase I of the study all fundamental lunar problems were considered, and an attempt was made to define all types of data which Apollo might be asked to gather on the moon. Next, Phase II provided a very comprehensive list of measurements and experiments that might be made to gather data on the moon. This list was then subjected to an evaluation in Phase III to determine which measurements would provide the greatest amount of scientifically and technologically significant data. The evaluation also considered future mission success and astronaut safety. In Phase III, all measurements, experiments, or observations of Phase II were evaluated in relation to five categories of significance as follows:

- (1) Those which define hazards affecting crew safety.
- (2) Those related to trafficability or future landing site selection.
- (3) Those related to defining the origin, nature, and age of lunar surface features.
- (4) Those related to lunar basing possibilities, especially water exploration.
- (5) Those related to all aspects of study of the earth-moon system.

The next step, Phase IV, was to compile a comprehensive list of instruments capable of making the measurements considered of greatest significance in Phase III. All instrumental measurements were then evaluated in Phase V on the basis of performance characteristics and on the basis of power, volume, and weight requirements. The instrument types were also evaluated in Phase VI on the basis of feasibility of operation in the lunar environment.

Finally, all data collected in previous phases will be assembled into matrix form, for use in the selection of optimum mission payloads based upon operational restraints which MSC will supply. The matrix assembly in Phase VII will provide for cross correlating certain experiments on the basis of a sequential order in which the experiments might be expected to be performed, and what might happen to future planned payloads after the data gathered on the previous mission has been analyzed and interpreted. Phase VIII will define, on the basis of the entire study, the experiments MSC may be asked to fly on a mission-by-mission basis. The best possible estimate will be made for each experiment of the requirements for weight, volume, power, telemetry, special handling, and any other special characteristics. The final report for this study is to be delivered to MSC by August 30, 1964.

In-house and Funded Studies

Preparatory studies now being conducted in-house or being funded through Manned Space Sciences Division may be divided into three categories: feasibility and background studies; operation and equipment development, including astronaut activity and instrumental measurement; and mission support studies.

The program has made every effort not to duplicate studies and development which have already been initiated or completed. An example of such studies would be the many experiments planned for the soft-landed surveyor, now in varying degrees of development, ranging from preliminary prototypes to flight-qualified hardware. Studies from the coming year's program are listed and described in the following paragraphs.

Effects of Lunar Environment on Mineralogy and Petrology

There may be mineral assemblages on the lunar surface unlike any found in a natural state on earth. Packaging samples of these materials might present special problems if they should prove unstable when removed from the lunar atmosphere.

Feasibility of Apollo Drilling Operations

A funded study will be conducted of the entire Apollo system to attempt to determine the type of drilling operations and the maximum depth and diameter of drill hole which might be feasible using the present LEM weight, volume, power, and other restraints.

Preservation of Lunar Profile Samples

A funded study will be recommended to determine how the astronauts can bring back intact a sample of the "Fairy Castle" structure in cross-section profile.

Radar Terrain Study of the Pisgah Crater Area

Another contracted study would utilize data on the Pisgah Crater area in California to determine the magnitude of the averaging of fine topographic detail by a radar beam. This area has already been mapped at a 25 centimeter contour interval. A computer program of the X, Y, and Z coordinates of points spaced at 1-meter grid intervals has been established.

Study of the Effect of Lunar Environment on Magma Generation, Migration, and Crystallization

Geologists at MSC have prepared a statement of work for a contracted theoretical study, concentrating on the vacuum, gravity, and temperature conditions of the moon, which could provide advance knowledge of possible differences in texture and morphology between lunar rocks and their terrestrial counterparts. This will be important for training astronauts in their task of geological exploration of the lunar surface.

In Situ Measurements by Geophysical Exploration Techniques

This study, to be conducted by the U.S. Geological Survey (USGS), will evaluate the use of geophysical exploration techniques for determining the distribution and physical properties of surface and subsurface rocks. Special emphasis will be placed on the value of electrical, electro-magnetic, gravity, and other measurements, in consideration of the limited mobility and traverse distance capabilities of the Apollo lunar surface exploration mission.

Investigation of Multiple Internal Reflection Technique for Measuring Absorption Spectra of Solids

A study will be recommended to OSSA to investigate the feasibility of designing a spectrophotometric analyzer based on internal reflection technique. If this technique can be used to measure the absorption spectra of solids, very little or no sample preparation would be required by the astronaut.

EXPERIMENTAL EQUIPMENT DEVELOPMENT

Lunar Surface Exploration Camera

Requirements for a hand-held camera for scientific exploration on the lunar surface are being compiled. This study will determine the camera's optimum design as dictated by the required capabilities, Apollo mission environmental conditions, and the spacesuited astronaut's limited dexterity. Some of the required capabilities are:

- (1) Interchangeable film
- (2) Color and black and white, stereo or single exposures
- (3) Capacity to identify objects 0.1mm in linear dimension
- (4) UV and IR photographs
- (5) Maximum weight - 7 lbs
- (6) Maximum volume - $\frac{1}{4}$ cu ft
- (7) Film capacity - 300 stereo pairs
- (8) Record of real time of exposure

Neutron Activation Analysis

This technique is under study for possible future application in post Apollo lunar exploration. The method has the potential capability of determining the elemental composition of the moon in regions inaccessible to the astronaut. Elemental composition is determined by bombarding the lunar samples with neutrons and measuring the resulting secondary gamma rays with an analyzer. Data would be telemetered back to manned lunar orbiting spacecraft or to a base. During the fiscal year 1964, the Radiation and Fields Branch initiated procurement of a laboratory prototype of a flyable pulse-height analyzer.

Lunar Surface Long-Life Meteoroid Detector-Analyzer

The Meteoroid Technology and Optics Branch will study the design and development of a lunar meteoroid detector-analyzer instrument. They will develop a laboratory breadboard system that will measure penetration flux, velocity, velocity vector, and mass of primary and secondary particles in the lunar atmosphere. The detector is to have an operational lifetime of at least one year.

X-ray Diffractometer

A surveyor prototype diffractometer is being purchased for in-house evaluation in terms of possible use by an astronaut. A study will be started on the possible use of multi-detectors to improve reliability and decrease operating time for obtaining X-ray diffraction patterns of each unknown rock or mineral sample on the lunar surface.

Solar Proton Monitor

After the LEM ascent stage departs, this instrument will be left on the lunar surface to provide long-term monitoring of solar flare proton events. The Radiation and Fields Branch is now developing a charged particle spectrometer for further evaluation.

Soil Mechanics Equipment

The development of equipment to obtain data for modifying the landing gear or pads of the Apollo LEM (if required) is the major emphasis of this proposed study. This equipment would supply measurements of bearing strength, shear strength, and compressibility.

Solar Wind Monitor

The Radiation and Fields Branch is attempting to determine the type of instrument to be left on the lunar surface for long-term monitoring of the solar wind and flux.

Hand Tool Requirements for Apollo Lunar-Surface Missions

Before manned scientific exploration can be undertaken on the lunar surface, existing geological hand tools must be modified to

reduce excess weight, to work in the lunar environment, and to minimize hazards in use. Proposals on this study will be requested within a few weeks.

Magnetometer

The astronaut will emplace a magnetometer on the moon's surface to provide long-term monitoring of the interplanetary and lunar magnetic field. The Radiation and Fields Branch is investigating to see if the magnetometer should be similar to those previously flown on interplanetary probes, and if special problems in emplacement may be encountered, because the astronaut has only a limited range from the LEM descent stage. It is also attempting to determine if the solar proton monitor, solar wind monitor, and magnetometer would provide better data if left in lunar orbit, rather than on the surface.

Mass Spectrometer

The Planetary Atmospheres Section will make an in-house evaluation of an existing coincidence mass spectrometer. This evaluation will help establish design parameters for an instrument to detect and determine any lunar atmosphere, and possibly, to vaporize and analyze lunar surface material for elemental composition.

Development of a Coring Device for Manned Lunar Exploration

Plans are being made for the development of a light-weight coring device capable of taking ten feet of core from any consolidated rock material on the lunar surface. The study is important not only to develop instruments, but also to provide data for spacecraft power requirements. The possible use of the LEM descent stage as a sink for heat dissipation will also be considered.

Lunar Surface Geodetic (Selenodetic) Experiments and Instruments

Instrumental measurements will be made by the astronauts to establish precise selenodetic control points. These data are necessary to produce more accurate maps and charts of the lunar surface, which should be an aid in further exploration.

MISSION SUPPORT STUDIES

The mission referred to here is the lunar surface scientific exploration phase of the Apollo mission.

Lunar Sampling and Sample Return

A study is proposed to determine the most advantageous methods for the collection and postflight return of surface material samples to be used for geological, chemical, and biological research. Every effort will be made to prevent any type of contamination of the samples and to deliver them to earth in their original condition.

LEM Descent Engine Chemical Contamination of Lunar Surface Sampling

There is a probability that the gases from the LEM descent engine will interact with materials on the lunar surface within the immediate landing area of the LEM. This recommended study would attempt to determine what effect this might have on the lunar surface sample-gathering procedure.

Lunar Surface Simulation Models

Two lunar surface simulations are to be used at MSC. One is a 625-sq ft indoor model which duplicates lunar surface albedo and lighting under various phases of earthshine (fig. 8-2). This model is located at Ellington Air Force Base. Construction has just been started on the second simulation at Site One (fig. 8-3). This will be an outdoor scaled model of 100 meter diameter, simulating lunar surface topography and geology. Studies will be made here of pressure suit mobility, mission time and motion studies with a LEM mock-up, astronaut scientific mission training, et cetera. Moon topography has been constructed and based on a reduced scale factor of today's state of knowledge. Lunar geology has been superimposed upon this topography according to the photo-geological categories developed by the U.S. Geological Survey (USGS), Branch of Astrogeology. Plans have been made to continually update this surface with each new addition of data from the Ranger, Surveyor, and Orbiter programs.

Selenology and Geosciences Astronaut Training Program

With the cooperation of six geologists from the USGS, Branch of Astrogeology, Training Series I classes for the 29 astronauts are now being conducted for the current program. The USGS personnel are instructing a Principles of Geology course, and MSC geologists are instructing a Mineralogy and Petrology course. The program also includes field trips to the Grand Canyon, the Big Bend Country in West Texas, and Philmont Ranch, New Mexico. Plans for Training Series II are now underway.

Cartographic Support of Lunar Surface Scientific Mission

This study will investigate the methods of recording precisely the activities of the astronauts on the lunar surface, and the materials from which mosaics or maps could be made, while withstanding the lunar surface environment.

Photographic Films for Lunar Surface Photography

In conjunction with the MSC Photographic Division, a study has been proposed to determine whether existing films would have to be used on the lunar surface or whether new films could be developed with broader exposure latitudes, broader spectral response, very thin emulsion, and other characteristics. This study could have a significant effect on lunar surface camera development.

Power Supply for Experiments

A contract will be monitored by the MSC Propulsion and Energy Systems Division to develop long-term dependable power supplies for lunar surface instruments or instrument packages. It appears that radio-isotope, thermonuclear generators will be able to supply up to 50 watts of power for long periods of time.

Telemetry Requirements and Capabilities

A funded study will be monitored by the MSC Instrumentation and Electronic Systems Division on telemetry and data handling capabilities required to support long-term, passive instrument packages. These instruments are to be emplaced, activated, and perhaps calibrated by the astronaut before he returns to earth. Data from these instruments would be telemetered to earth.

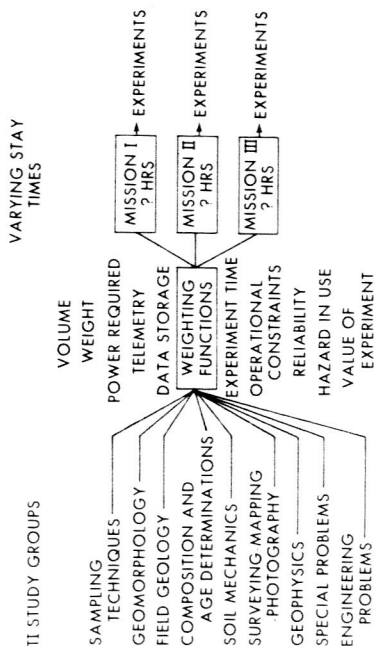


Figure 8-1



Figure 8-3



Figure 8-2

9. LUNAR ORBITAL EXPLORATION

By James H. Sasser

While it is true that many experiments and measurements can be made only on the lunar surface, it is also true that many other experiments can be performed best from lunar orbit; particularly, when lunar samples and data have already been collected and evaluated. Exploration from lunar orbit seems very attractive when it is realized that from an orbital altitude of 80 nautical miles, about one-third of the moon's surface could be in the view of sensors during just one orbit.

The main purpose of a lunar orbital survey mission would be to acquire data to produce accurate, large-scale lunar maps. Present ability to produce detailed maps of the moon is limited by the resolution attainable in lunar photographs or in visual telescopic observation.

Figure 9-1 shows an enlargement of a photograph of the crater Aristarchus. The apparent diameter of Aristarchus is about 40 kilometers, and its depth is just over 2 kilometers.

The most complete map series of the moon today is the 1:1,000,000 scale LAC series produced at the U.S. Air Force Aeronautical Chart and Information Center (ACIC). Figure 9-2 shows the Aristarchus area as portrayed on the 1:1,000,000 scale LAC chart. More details are added to the base maps by visual telescopic observations.

Figure 9-3 shows what is probably the most detailed drawing today of any area on the moon. This was prepared at a scale of 1:500,000 by ACIC personnel at Lowell Observatory to report the lunar color phenomena observed in October and November 1963.

The pictures in figures 1, 2 and 3 illustrate how the amount of lunar detail increases when the map scale is merely doubled. Yet the smallest features visible in the 1:500,000 portrayal still represent more than 500 meters on the lunar surface.

The microrelief of the lunar surface needs to be determined down to the scale of meters and decimeters. It has been suggested that the astronauts be provided with 1:25,000 scale maps of lunar landing areas for geological exploration purposes. The 1,000-foot traverses of a typical scientific mission would only represent $\frac{1}{2}$ inch at this scale.

Plans are being made to furnish the astronauts with 1:1,000 scale photomosaics of areas that must be explored on foot. Only high

resolution photography obtained from lunar orbit can define the micro-relief of the moon on the meter-decimeter scale and make this possible.

Many methods of remote compositional analysis are being studied by scientists throughout the country. Among these methods are infrared sensors and multispectral photography. The infrared sensors can be used to detect thermal anomalies, as well as to perform compositional analyses. The multispectral photographic technique, for those who may not be familiar with it, utilizes many cameras to photograph simultaneously the same surface area. By means of filters and films of different spectral sensitivity, each camera can photograph the area in a different spectral region. The resulting images can be added or subtracted in many ways for interpretation of the photographs.

The picture in figure 9-4 shows an experimental composite color photograph of the moon that was prepared from images obtained with a 9-lens camera. The next picture in figure 9-5 is a photomosaic for comparison.

When enough is learned about lunar surface materials to interpret photos such as this one, it will be possible to locate surface materials with unique reflective properties. The techniques of remote compositional analysis will play a large role in the search for lunar resources, and the selection of locations for lunar bases. These methods will also be valuable in the geologic mapping of the moon.

Radar measurements and gravity gradient measurements have also been suggested as lunar orbital experiments. The former may be used for topographic mapping and for measurement of dust thickness (if there is dust); the latter may detect gravity anomalies to make possible deduction regarding the subsurface structure. These measurements can also be of great value in improving knowledge of the size and shape of the moon. Such knowledge is necessary for accurate lunar mapping and charting. The existing uncertainties of several thousand meters in the positions of lunar control points are due, to a large degree, to uncertainties in the size and shape of the moon, the inclination of its axis of rotation, and the magnitude of its physical librations. Better values for all of these must be found, and more accurate lunar control established, before it will be possible to realize the navigational accuracies available in existing inertial guidance systems.

Since aerial photography from lunar orbit will be necessary, studies are being made to determine the best cameras for such work. A study of aerial camera systems suitable for manned lunar survey missions was begun by ACIC in November 1963. The results of this study show that it is possible, with existing aerial camera systems, to obtain photography

from lunar orbital altitudes from which the lunar microrelief down to one foot in size can be identified and measured.

A study of methods of interpretation of lunar photography is scheduled to begin soon. The reasons for the unusual photometric properties of the lunar surface are not known. If these same properties are still exhibited on high-resolution photographs of the moon, however, they could cause problems in the acquisition and interpretation of lunar photographs. This study will evaluate the effects of photometric properties on exposure times and camera apertures, and compare stereoscopic and monoscopic methods of extracting data from simulated lunar photographs.

Once numerical data are available concerning surface slopes, prominences, or depressions on the lunar surface, a question arises about the method to be used to describe the different types of surface areas. The quantitative methods used should not only describe single factors, such as local slope, but should also provide an index of the combination of factors that would influence the success of surface missions. The problem is similar to that encountered in military trafficability studies. This study of mathematical methods of describing lunar terrain should yield a way of describing areas of the lunar surface in terms of their suitability as possible landing areas. The same methods would be useful to the photogeologist in describing the morphology of lunar areas, and in evaluating possible exploration areas in terms of astronaut mobility.

Investigation of the feasibility of lunar compositional mapping by means of ultraviolet spectroscopy is underway. Many studies are being made by others throughout the country to determine what data can be obtained by using infrared sensors. However, if the lunar surface is covered by a fine dust of around 50 micron particle size, the surface will radiate as a black body in the infrared. Many lunar scientists believe that the surface of the moon is covered by this finely divided material, so a method of remote compositional analysis, not affected by fine dust, may be required. Ultraviolet wavelengths, an order of magnitude shorter than infrared wavelengths, offer a method of compositional analysis whereby dust would not adversely affect the result. In particular, the use of UV emission lines in the region between 2,000 to 3,000 Å appears promising since the lunar surface is a poor reflector of solar radiation in these wavelengths.

Investigation is being made of the photometric, polarimetric, thermal, and dielectric properties of suggested lunar surface materials. By eliminating those materials whose properties do not match those of the moon in any one of these areas, the range of possible materials can be narrowed considerably. Much work has been done in the separate areas

during the search for possible lunar materials, but the combined approach - that of attempting to correlate all measured data in one lunar surface model - has yet to be attempted.

Present knowledge of the size and the shape of the earth was obtained only by many thousands of man-years of effort. It would certainly not be practical to attempt the same process of measuring the long arcs of geodetic triangulation on the moon. Fortunately, manned orbital spacecraft can provide a base from which both the size and shape of the moon can be determined to accuracies approaching or exceeding knowledge of the earth. Direct distance measurements to the lunar surface from lunar orbital satellites will allow continuous profiles to be made, using the satellite orbit as a reference base. From satellite orbits of 100 miles or more above the surface, gravity anomalies at or beneath the surface will cause such small perturbations in successive satellite orbits that uncertainties in the lunar radii can be reduced to only a few tens of meters. Radar and laser terrain profile recorders are to be investigated during the coming year to determine which would be best for this purpose. The laser is attractive in this regard because of its high resolution and reliability. Radar systems, on the other hand, offer the benefit of measuring distance not only to the visible surface, but through any highly porous surface layer.

A feasibility study is being negotiated at the present time for a lunar contour mapping system. This system can be used to range, record, and store information on subsatellite topography on both the dark and sunlit sides during many orbital passes around the moon.

One of these, or some combination of these methods, will surely be required to improve knowledge of the figure of the moon.

On earth, geodesists frequently make astronomic position observations and apply corrections for deflection of the vertical to establish geodetic positions. If it were practical to determine the angle between the local vertical and the axis of an orbiting mapping-stellar camera system at the same instant, the position of the center of each successive photograph could be determined independently. This would eliminate the normal error propagation found in photogrammetric control extensions. The gravity gradiometers proposed to measure sub-surface anomalies are theoretically capable of indicating the direction of the local vertical. During the coming year, studies are being planned to determine the best type of vertical sensor to be used during lunar orbital survey missions.

With the successful completion of a lunar orbital survey mission, it is quite possible that one of the basic aims of the national space exploration program may be realized - the origin and history, not just of the moon, but of the entire solar system, may at last be determined.

NASA S-64-3991

ARISTARCHUS
PHOTO



Figure 9-1

NASA S-64-3998

ARISTARCHUS
USAF CHART

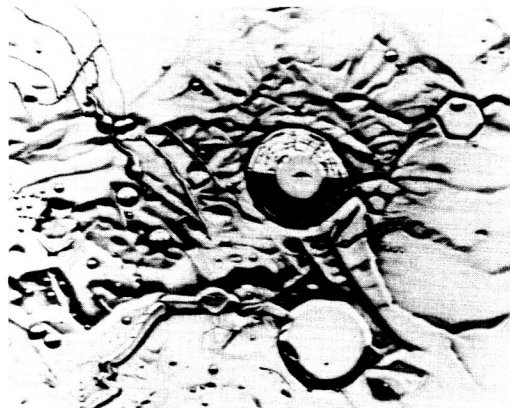


Figure 9-2

NASA S-64-3999

ARISTARCHUS
NEW USAF DRAWING



Figure 9-3



Figure 9-4

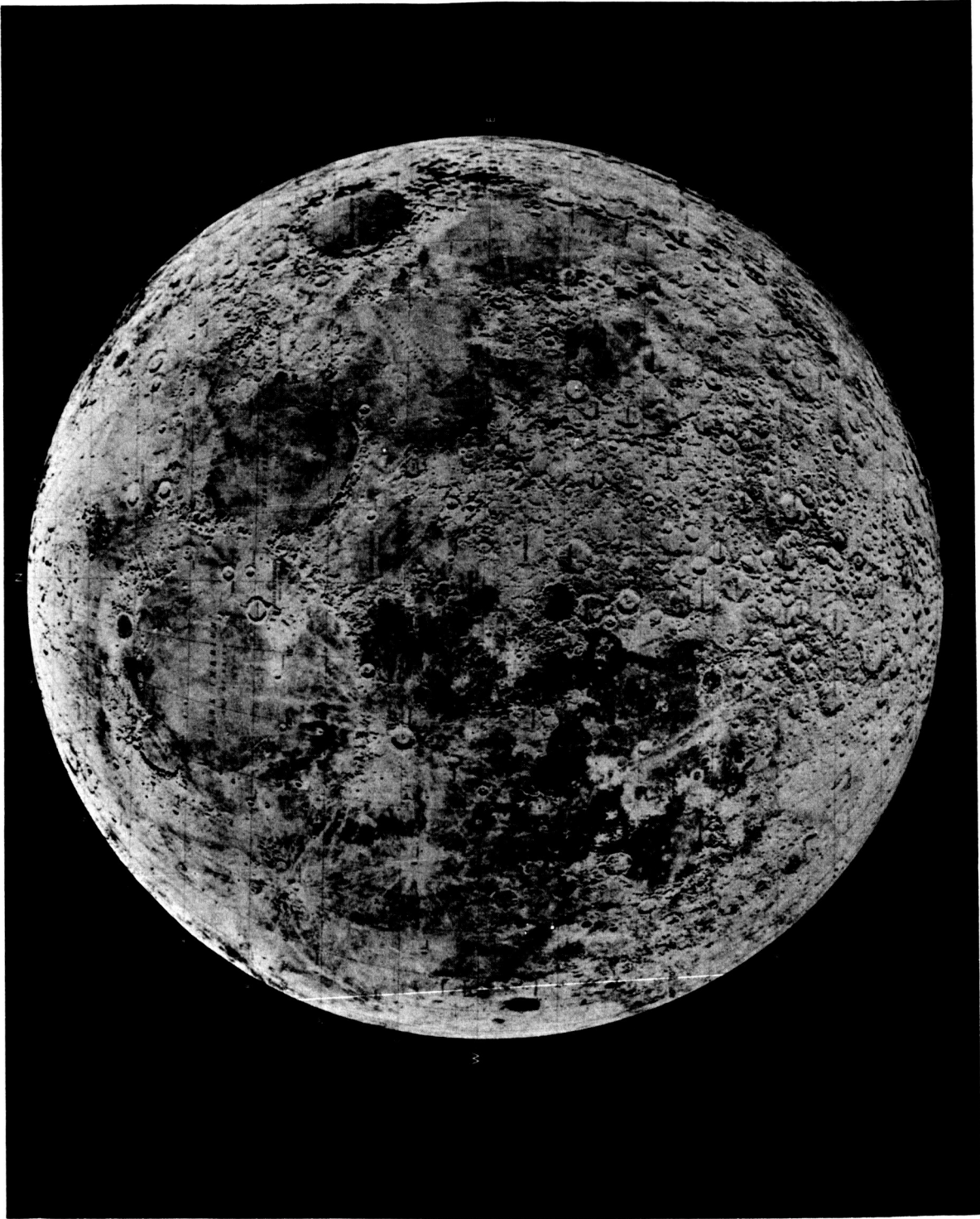


Figure 9-5

10. SPACECRAFT CAPABILITY FOR LUNAR ORBITAL SURVEY

By Donald Bresie and Rene A. Berglund

SUMMARY

The ability of the Apollo spacecraft to perform a lunar orbital survey mission is discussed, and a typical 14-day mission is presented. Suggested sensor systems such as high resolution cameras, electronic sensors and surface probes are described, along with an equipment module used to house them.

INTRODUCTION

The primary mission of the NASA Apollo program is a manned landing on the lunar surface. The initial Apollo landing will be supported by unmanned programs such as Ranger, Surveyor and Orbiter to assure the success of the initial landing. It is rational to assume that after the initial landing, there will be further lunar exploration. In view of the inhospitable lunar environment, it can also be assumed that establishing and maintaining human beings on the lunar surface will be difficult. The problems of establishing a base will require the development of techniques to explore the lunar surface from an orbiting spacecraft. This exploration will allow men to visually observe and photographically record the lunar surface and, with the aid of additional sensors, measure and record the lunar environment. This record will provide the information necessary to select the most promising areas of scientific interest and determine their accessibility from a suitable lunar excursion module landing site. The inaccessible areas of interest must be explored from orbit.

THE MISSION

The Lunar Orbital Exploration Mission is suggested to fulfill these goals. The mission is not a presently scheduled Apollo mission but in-house studies show that it would be very beneficial. It can be briefly described as a non-landing, scientific mapping and survey mission. The major advantage of the mission is that, unlike landing missions, there is no shortage of payload capability for carrying experiments. Information is to be gathered with high quality photographs, electromagnetic

measurements and visual observations. Surface probes from lunar orbit may also be used.

The proposed mission, basically Apollo, described in this presentation will follow these guidelines:

- (1) It will come after the presently scheduled landing missions.
- (2) The mission will provide 14 days in lunar orbit for a crew of three.
- (3) Basic Apollo hardware will be used with only minor modifications.
- (4) Instead of the lunar excursion module, an equipment module will be carried to house the photographic, optical, and electronic equipment.

As shown in figure 10-1, the lunar exploration mission will begin as an Apollo mission with launch into earth orbit. The translunar trajectory will be similar to a landing mission. At midcourse, there will be a maneuver to position the space vehicle to make a polar lunar orbit instead of an equatorial orbit as in the landing mission.

The reason for choosing a polar orbit, shown in figure 10-2, is to obtain greater surface coverage. On a 14-day mission, for example, the spacecraft will pass over the entire lunar surface, though only half of it is lighted. This can be done without the aid of plane-change maneuvers. The coverage is obtained by the moon's rotation with respect to the spacecraft orbit.

Another advantage of a polar orbit is that it lends itself to high resolution photography. In order to get good photography, a lighting angle of between 10° to 40° from the horizontal is needed, with an optimum angle of about 18° . This allows interpretation of object heights and surface slopes.

Figure 10-3 shows that if the orbit passes over the subsolar point, a good lighting coverage of 60° latitude per orbit can be expected. As the longitude of the orbit is shifted to one side or the other of the subsolar point, then the coverage increases. An orbital orientation of 50° from the subsolar point gives the maximum good lighting coverage. Since the orbit is space-fixed, once the orbit is established, it will remain fixed with respect to the good lighting area. There will be a change in the orientation of the orbit of 1° per day due to the motion of the earth-moon system about the sun.

THE SPACECRAFT

Now that the mission has been briefly discussed, the vehicle needed to accomplish it will be described. Figure 10-4 shows the launch configuration. There will be relatively few changes to the command and service modules. The same launch vehicle will be used. The lunar excursion module will be omitted, and in its place will be an equipment module used to house all the various additional equipment. This equipment module has no additional systems other than those needed to support the scientific equipment. Life support equipment is provided by the command and service modules. In this way, the most versatile spacecraft is provided, and it has the simplest experimental package interfaces possible. The probe rack shown will be used to support this equipment module inside the booster adapter. Naturally, there will be some change in the fueling of the booster and service module due to the change in weight of the payload as a whole.

The equipment module shown is much lighter than the previously used lunar excursion module. Because of this, there is an excess booster payload capability of approximately 20,000 pounds. This weight might be used for additional experiments and contingencies.

After launch and injection into the translunar trajectory, the adapter will be jettisoned as in the Apollo landing mission, and the command and service modules will dock to the equipment module as shown in figure 10-5. This configuration will be maintained throughout the lunar phase of the mission. After injection into lunar orbit, two men will transfer into the equipment module to operate the cameras and electronic equipment. Presumably, there will be a "shirt-sleeve" atmosphere inside.

The inboard profile of the equipment module (fig. 10-6), shows the location of the cameras and equipment. The cameras operator (8) selects the area to be surveyed with the aid of a viewfinder (3). The cameras (1 and 2) are pointed by orienting the entire spacecraft. The second crewmember (7) operates the electronic equipment (4 and 5) and launches the surface probes (6), if carried.

THE SURVEY SENSORS

Some of the optical systems that might be used in a lunar orbital exploration mission were investigated. A short-focal-length camera will be used for general cartographic photography. It will give continuous coverage of the entire lighted lunar surface. A short-focal-length stellar camera will take position reference data. A pair of

long-focal-length cameras will give stereographic high resolution coverage of specific areas of interest. There will also be a viewfinder which will have both high and low resolution viewing modes with varying magnification power in each. The low resolution mode will have a lower magnification limit of unity. The high resolution mode will have maximum magnification sufficient to resolve 2-foot objects on the surface, or about 50 power. The viewfinder will be used to determine the areas to be covered by high resolution photography.

With a conservative estimate of film payloads, it will be possible to photograph 182° longitude of the surface of the moon with the mapping camera or about 7,000,000 square miles. Due to the greater film usage, a more limited coverage can be obtained with the high resolution cameras. An estimated 300,000 square miles will be covered or about 30 sites, 100 miles square. These high resolution photographs will be taken in areas of optimum lighting to obtain the best pictures possible.

In addition to photographs, there would also be sensors to measure various factors. Those sensors investigated could be accommodated in the equipment module. They could measure meteoroid flux, electromagnetic radiation and gravitation fields. There is some possibility of using sensors such as radar for dark-side mapping. The limiting factor for such a sensor, however, will be the power requirements.

The most serious constraint with regard to coverage is the quantity of film that can be returned to earth. The figures concerning coverage assume only 80 pounds data returned to earth. Since this weight may be conservative, it is conceivable that much greater coverage of the moon is possible. Since the limiting factor is reentry weight, much of the data could be telemetered to earth. Most electronic data can be handled in this manner. However, little transmission of photographs is anticipated due to the penalty in resolution.

SURFACE PROBES

The development of a surface probe for determining lunar bearing strength is planned for early Apollo missions. This surface probe shown in figure 10-7 could also be adapted to deliver other experiments. The following specifications apply to the surface probe:

Ballistic, unguided trajectory with spin stabilization.

Lunar impact velocity = 200 fps.

Thrust loads = 8g's

Impact loads = 2,000g's or less

Payload - 20 to 25 pounds

Payload envelope - 1' sphere

A balsa wood impact limiter surrounds the payload and protects it at lunar impact. As shown in figure 10-8, this balsa is blown away with explosive charges after impact. An erection mechanism is available to right the payload. If experimental requirements demand it, more complex soft landing probes similar to Surveyor could be designed for this mission.

EXTENDED MISSIONS

Since one-half of the lunar surface can be photographed in a 14-day mission, one might ask why a longer mission such as a 28-day mission is not suggested to cover more surface area. The answer lies in the fact that missions extended beyond 14 days would require some major modifications to present hardware design. For example, additional CO₂ absorption capability would be necessary for environmental control. Larger power supply reactant tanks would be needed. In addition, more fuel cells would be required since the longer mission would exceed the expected life of a cell. In-flight starting capability of the spare cells would be necessary. These longer missions will be very desirable from the standpoint of greater coverage and lower cost per unit area covered. There are other methods of obtaining greater coverage. An additional propulsion capability is one approach.

With more propulsion, the module is not limited to the 13° per day provided by the moon's rotation. More low resolution, cartographic photographs can be taken per unit time. However, since this propulsion could take the spacecraft out of the good lighting areas, this technique is not applicable to high resolution photography. This propulsion capability will probably require an additional stage which may be provided by a modified version of the LEM descent stage. The 14-day mission as described here, or a mission with additional propulsion, or with extended stay time, are all possible. The evolution of the state-of-the-art and the degrees of success of presently planned Apollo missions will be the determining factors in deciding which is best.

CONCLUDING REMARKS

The important point to remember is that Project Apollo can provide a maneuverable spacecraft and trained personnel to perform lunar orbital exploration. Photographs and electronic survey sensors coupled with man's visual ability will provide means of recording the lunar surface characteristics. The capability of a lunar orbital exploration mission has been discussed and a general-duty experiment module to accomplish the mission has been described, based on the somewhat naive concept of what experimental equipment might prove useful. It is really up to the scientific community to generate the specific requirements which will determine the actual need and uses for such a mission. It may well be that after the initial lunar landings, the information gained will show that the scientific exploration of the lunar surface can be done for the most part from lunar orbit. In any case, such a mission as described will be required to select the sites for more extensive surface exploration.

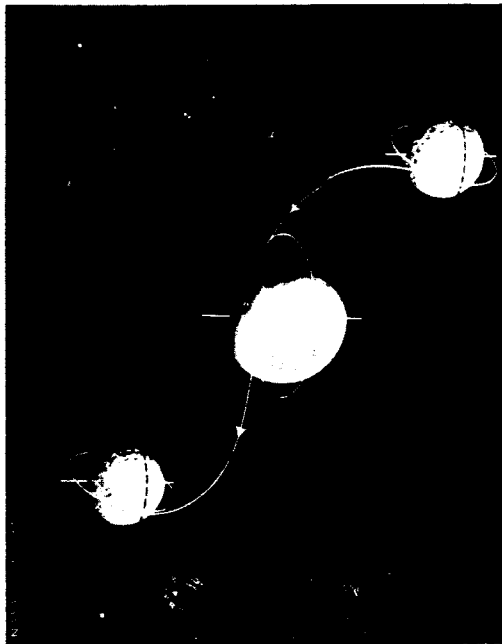


Figure 10-1

NASA S 64-3852

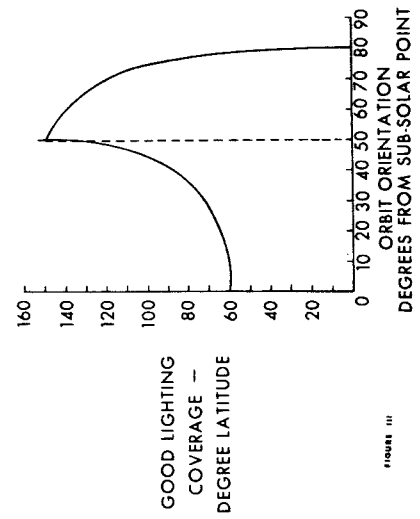


Figure 10-3

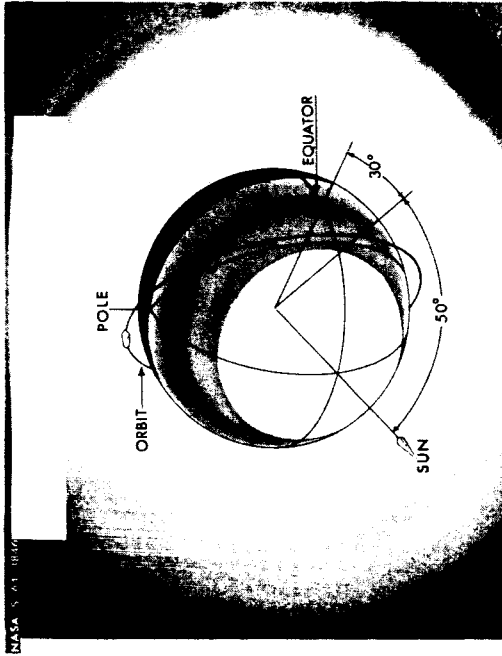


Figure 10-2

NASA S 64-3845

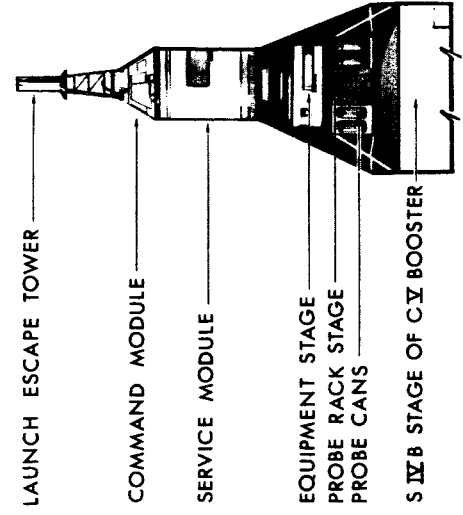


Figure 10-4

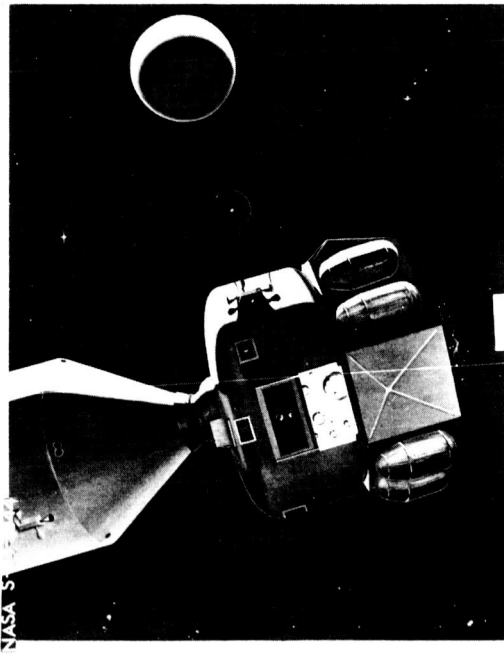


Figure 10-5

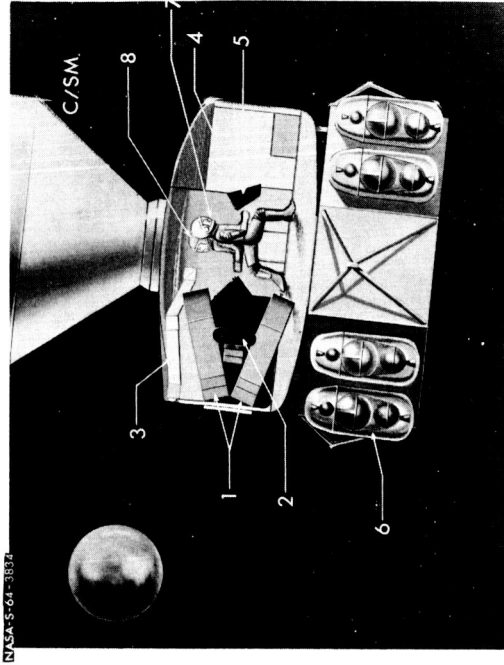


Figure 10-6

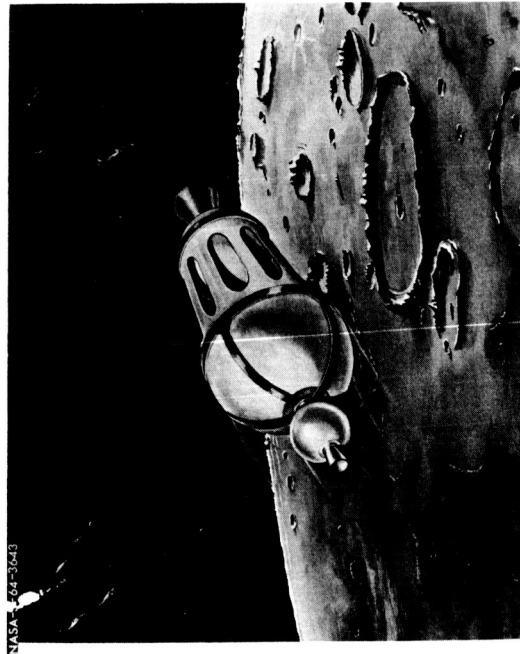


Figure 10-7

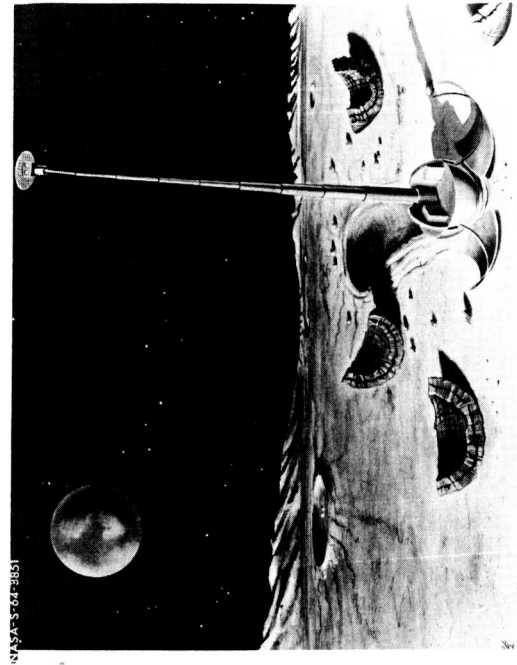


Figure 10-8

11. LUNAR ATMOSPHERIC MEASUREMENTS

By Dallas E. Evans

INTRODUCTION

Man's initial trip to the moon will allow him to observe the results of cosmological processes which have been in existence since the moon's formation. It is extremely important that he use this giant cosmological laboratory with great care and not change its nature so that its primitive state will be unknown to future scientific investigators. Knowledge of the primary lunar gases can furnish valuable information relating to the geological structure and history of the moon.

The moon's atmosphere is one environmental factor which may be altered by rocket exhaust gases during the first and succeeding lunar missions. It is important, therefore, that definitive observations be made of the undisturbed and unmodified atmosphere of the moon as well as observations of the changes produced by rocket gases.

There will be opportunity during the trans-lunar phase of the Apollo mission, and during the lunar orbital phase, for an astronaut to make observations of the primary lunar gases and thereby increase man's understanding of the formative processes of the planetary system. Moreover, during the orbital phase and the transearth phase, observations can be made of the interaction and diffusion of the LEM and command-service module rocket exhaust gases with the primary lunar gases. Such observations will be valuable in determining the life times of rocket gases in the moon's atmosphere, thereby providing a basis for determining the buildup of rocket gases in the lunar atmosphere for future missions to come.

Another environmental factor which may be altered by rocket gases during the first and succeeding lunar missions is the accumulation of condensed rocket gases upon possible existing primitive deposits of frozen water and carbon dioxide in permanently shaded regions on the lunar surface. During future lunar surface exploration into these shaded regions, the question may arise as to whether any discovered frozen constituents were primitive in origin or products of rocket gases, or possibly both. Knowledge of the diffusion and flow of rocket gases around the moon's surface could possibly aid in determining the answer.

PREVIOUS EXPERIMENTAL RESULTS

Many investigators have gathered experimental data in attempting to gain some measure of the existence and structure of the lunar atmosphere. The best that terrestrial based experiments have been able to accomplish is to determine the probable upper limits of the moon's atmospheric density as estimated by the investigative techniques shown in table I. For example, the 10^{-13} experimental value, which is used by many authors in theoretical lunar atmosphere studies, was obtained when the moon passed in front of the Crab Nebula. The latter is considered a radio source, that is, it emits electromagnetic waves in the radio frequency band. Since the moon's atmosphere is of low density and exposed to ionizing solar radiation, it should be highly ionized. Therefore if the radio waves from the Crab Nebula pass through the ionized lunar atmosphere, they should be refracted, and the measure of the refraction would be related to the amount of ionization.

It should be pointed out here, however, that one authority strongly suggests that the radio star occultation technique is misleading since an assumption must be made concerning the amount of ionization which is dependent on the gaseous composition of the moon's atmosphere. If the moon's atmosphere is composed primarily of argon, which has a high ionization potential, it may not be highly ionized to an extensive depth. This would, therefore, lead to a higher value of lunar atmosphere density than is deduced by radio star occultation methods.

THEORETICAL CONSIDERATIONS

It is not the intent of this paper to propose or propound any specific or unique theory concerning the existence of a lunar atmosphere, nor speculate concerning the most likely structure of the lunar atmosphere as suggested by other authors. What has been attempted is to make a summary of lunar atmosphere composition as proposed by these previous authors in table II.

The main purpose of such a summary is to obtain some idea of the ranges of gas composition and their densities as well as the ionic values required to provide a guide line for possible instrument techniques to be considered for atmosphere measurements.

As has been shown, previous authors generally have not agreed on the composition of the moon's atmosphere. A lack of actual data allows a wide variety of initial assumptions to be made. The difference in

these initial assumptions, principally in assumed sources, are the basis of the disagreement among the proposed atmospheres.

The principal mechanisms of loss of constituents are generally agreed to be thermal escape, collision processes with the solar wind, and electrostatic repulsion of ions. Most of the recent models consider these three processes. The solar wind is also considered a major source of lunar atmosphere constituents as well as a mechanism for their ejection.

Other than the solar wind, there is little consensus among authors on sources to be included in the atmosphere model. The constituency of the solar wind is generally taken to be the same as relative stellar abundances, but there is admitted uncertainty in this supposition. Estimates of surface and meteoritic outgassing, volcanic activity, surface sputtering and fission production of heavy gases vary widely and generally lead to a corresponding variety in the resultant lunar atmosphere models.

Until substantial improvements are made in the knowledge of various mechanisms related to the lunar atmosphere, any model which might be derived will be subject to considerable uncertainty.

DETECTION CONSIDERATIONS

The characteristics of the lunar atmosphere may be studied with both mass and optical spectrometric techniques. There are limitations to both techniques.

Mass analysis may be performed on either the neutral or the ionized component of the atmosphere. Mass spectrometry at present offers the only technique which is capable of determining isotopic abundance ratios and mass distribution in the lunar atmosphere.

By measuring the ionic components rather than the neutral components, the following problems are considerably simplified:

- (1) The effects of vehicle outgassing
- (2) The dissociation of complex molecules during the ionization process
- (3) The recombination of complex products in the spectrometer prior to analysis

The optical techniques would offer the major advantage in that the measurements may be performed at larger distances from the vehicle than possible with mass spectrometer techniques, thus the precise altitude of the vehicle is no longer important.

Before deciding whether to use mass or optical spectrometric techniques during an Apollo mission, the different phases of the mission profile and the operational requirements should be considered.

Translunar Phase

During this phase the command-service modules and LEM have been ejected from earth into a trajectory to intercept with the moon. The travel time is a nominal three days, and therefore would permit adequate time for the astronauts to obtain lunar atmosphere measurements by means of optical techniques. This data would be that of the primitive, or primary, lunar atmosphere within the limits of the optical system and would provide a comparative check against data obtained during the other mission phases. At the end of this phase the command-service module retro rocket will be applied in order to insert the Apollo vehicle into lunar orbit, and as a result, some of these rocket gases may interact with the lunar atmosphere and thus initiate the first lunar atmosphere contamination reaction. Other smaller correction rocket burst may be required to achieve the correct lunar orbital altitude.

Lunar Orbit Phase

Once in lunar orbit, both optical and mass spectrometer techniques may be used. The mass spectrometer would be preferred in obtaining lunar atmosphere composition data at the lunar orbit altitude; whereas, the optical techniques would be able to obtain information at remote positions from the command module. Continuous monitoring by the command module in lunar orbit of the LEM rocket gases during both the LEM descent and ascent stages would provide information regarding the diffusion and flow of rocket gases around the lunar surface to the dark side (heat sink) of the moon.

Transearth Phase

During this phase the command-service module ejects at the proper time from lunar orbit into a trajectory to intercept with earth. During this ejection from lunar orbit more rocket gases will be injected into the lunar atmosphere; consequently, it would be desirable to investigate the lunar atmosphere before the command and service modules separate and

thereby obtain data by optical techniques as to the possible total rocket gas contamination of the lunar atmosphere. Such data could also provide information relating to the lifetime of rocket gases in the lunar atmosphere.

It has been suggested that it might be desirable to leave an optical and mass spectrometer system aboard the abandoned LEM in lunar orbit with sufficient telemetry so that continuous monitoring, at the LEM orbital altitude, could be made to investigate the effects of solar flare events upon the lunar atmosphere.

Lunar Surface Phase

Although the lunar surface phase logically comes before the trans-earth phase, it was intentionally left until last. After the LEM lands on the lunar surface, a coincidence mass spectrometer positioned by the astronaut would be most desirable to obtain lunar surface atmosphere composition. The same coincidence mass spectrometer with proper design could be used to analyze lunar surface material composition as well. The coincidence mass spectrometer is a relatively new concept and some of the outstanding characteristics claimed by its developer are as follows:

Will measure masses from 1 to 10,000

Has 1,000,000 times greater absolute sensitivity than any other existing mass spectrometer

Can measure concentrations of less than one part per million

Can analyze gas mixtures in which the total pressure is as low as 10^{-18} torr

An analysis of the lunar atmosphere at the moon's surface will have to contend with many factors such as outgassing of the LEM, astronaut's spacesuit and other experimental packages, as well as possible emission of LEM retro rocket gases which may be absorbed temporarily into the lunar surface. However, by removing the spectrometer sufficiently far from the LEM these potential problems could be obviated.

In conclusion, it is also recognized that the lunar atmosphere may be contaminated to some degree before the Apollo mission by Ranger and Surveyor unmanned vehicles. Nevertheless, with sufficient information of the lunar atmosphere from the Apollo mission, it should be possible to determine the fraction of contamination due to the small amount of long life time gas constituents from these previous space vehicles.

TABLE I. - MAXIMUM DENSITY OF LUNAR ATMOSPHERE

Author	Method	Maximum density of lunar atmosphere. (Density of earth's atmosphere at sea-level = 1)
Russell, Dugan and Stewart	Absence of twilight	10^{-4}
Lipski	Photography of twilight in green light, with a polarimeter	10^{-4}
Lyot and Dollfus	Photography of twilight in yellow light, with a 20 cm coronagraph	10^{-8}
Dollfus	Photography of twilight in orange light, with a 20 cm coronagraph and Savart-Lyot polariscope	10^{-9}
Elsmore and Whitfield	Refraction of radio waves in lunar ionosphere	10^{-12}
Costain, Elsmore, and Whitfield	Refraction of radio waves in lunar ionosphere	10^{-13}
Hazard, Mackey, and Skimmins	Refraction of radio waves in lunar ionosphere	10^{-13}

TABLE II. - PROPERTIES OF THEORETICAL LUNAR ATMOSPHERES

Author	Density (In terms of terr. at sea level)	Possible gaseous constituents considered
Elsmore	$< 10^{-13}$ 10^3 e/cm^3	
Vestine		H_2O , CO_2 , SO_2 , A, N_2
Edwards and Borst	Elsmore's value	Kr, Xe
Herring and Licht	$< 10^{-11}$ $\text{N}_0 \approx 10^8/\text{cm}^3$ and Elsmore's value	A, H_2O , CO_2 , SO_2 H ($4 \times 10^4/\text{cm}^3$)
Opik and Singer		Kr, Xe (determined by solar wind)
Singer		$\text{H} \approx 80/\text{cm}^3$ $\text{e}_\text{N} \approx 10^3/\text{cm}^3$ (only gas from interplanetary space)
Watson, Murray and Brown	Elsmore's value	H_2O vapor ($3.5 \times 10^4 \text{ mole/cm}^3$) ion den. $\approx 10^2/\text{cm}^3$ Hg, Kr, CO_2 , SO_2 , Hcl, H_2O , NH_3
Nakada and Mihalov		N ($10^5/\text{cm}^3$), O ($10^6/\text{cm}^3$), Ar ($10^4/\text{cm}^3$), and e_N ($8 \times 10^5/\text{cm}^3$)
Opik	Elsmore's value	Max $\text{e}_\text{N} \approx 2,300/\text{cm}^3$ obs. $\text{e}_\text{N} \approx 1,400/\text{cm}^3$ N_0 ($10^5/\text{cm}^3$) species, with $\text{H}_2 \approx 0.12$, $\text{H}_2\text{O} \approx 1.4$ $\text{CO}_2 \approx 1.4-3.4$, various (volcanic) ≈ 0.1 with all $\approx 3-5$, also O and N
Weil and Barasch	Elsmore's value	e_N (max) $\approx 400/\text{cm}^3$ gases not considered